4 PILOT STUDY SUMMARY AND CONCLUSIONS

SUMMARY

Our preliminary examination of ozone and meteorological data collected in the South Coast Air Basin indicates the presence of four distinct source history categories, each of which is associated with a unique set of meteorological and aerometric features:

Typical Pattern: Onshore pressure gradients resulting in a vigorous sea breeze regime penetrating inland through the San Gabriel Valley characterize this pattern. These conditions, which primarily occur in the middle of the ozone season when daytime heating in inland areas is strongest, result in basin-wide ozone peaks in the San Gabriel Valley and Inland Foothill subregions that are close to the seasonal maximum. Both relative and absolute concentration levels in the coastal and metropolitan areas and in the mountains are lower under this pattern than under other types of conditions. This pattern seems to correspond closely to the "normal sea breeze" regime identified by Godden and Lague (1983).

Eddy Pattern: This pattern is associated with southerly or southwesterly coastal winds that lead to a greater inflow of ozone and precursors into the San Fernando Valley and up the adjacent mountain slopes than occurs on Typical Pattern days. Ozone concentrations in the Mountain subregion reach their highest seasonal levels and are near the basin-wide maximum under these conditions. However, mountain concentrations, along with those in the San Gabriel Valley and more easterly locations, are not as high under this pattern (which tends to occur early in the ozone season and in conjunction with cooler temperatures) as those associated with the Typical Pattern.

Southern Route Pattern: Under certain synoptic conditions that are most likely characterized by a northerly or northeasterly flow aloft,* the strength of the

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* Although data on winds aloft were not available to us for this study, the occurrence of negative Lancaster to LAX surface pressure gradients and low inversion heights, in conjunction with this pattern, suggests the presence of northerly winds.

sea breeze is reduced from that of the Typical Pattern and directed further to the south, so that ozone concentrations in coastal and metropolitan areas are higher in relation to those in other parts of the basin. The seasonal maximum concentrations in the North and South Coast subregions occur under this regime, and concentrations in the Metropolitan subregion are higher on average than under other patterns. The high concentrations associated with this pattern in the heavily populated western portions of the basin make it particularly important from a population exposure standpoint.

Offshore Pattern: Occasionally, synoptic conditions will lead to an inverse pressure gradient pattern that promotes a weak offshore flow. If the gradients are too large, a full Santa Ana condition results and clean, dry continental air invades the entire basin resulting in very low ozone concentrations. However, if the gradients are weak, the opposing sea breeze will produce stagnation conditions in much of the basin with very weak onshore flow immediately along the coast. This results in relatively high ozone concentrations in the Coastal and Metropolitan subregions with much lower than average readings in the easternmost portions of the basin. This pattern clearly corresponds to the "marginal Santa Ana" regime identified by Godden and Lague (1983).

Not every day in the ozone season displays all of the key characteristics of one of the four patterns described above. In particular, we identified a number of days that display some of the characteristics of the Eddy Pattern while at the same time retaining features in common with the Typical Pattern. In most cases, these days exhibited relative ozone concentrations similar to those characteristic of the Eddy Pattern but meteorological features more in-line with what one would expect to find on Typical Pattern days. We refer to these days as Partial Eddy Pattern days. In a similar vein, Partial Southern Route Pattern days were found to share some of the characteristics of both Southern Route and Typical Pattern days. These days are notable for their very high ozone readings in the Inland Metropolitan, San Gabriel Valley, Inland Foothill and Inland Valley subregions, making Partial Southern Route days the highest ozone days in much of the basin.

Our comparison of the distributions of absolute ozone concentration levels within each source history category revealed statistically significant differences between categories in the average concentration levels in all subregions except the San Fernando Valley. In the North and South Coast, Metropolitan and Inland Metropolitan subregions, between 39 and 52 percent of the variance in the subregion average daily maximum ozone concentrations can be attributed solely to the source history classification. In the subregions lying further inland, only 22 to 30 percent of the variance can be so attributed. In the San Fernando Valley, there is almost no difference in concentration levels from one category to the next and the classification of days into source history categories accounts for only 6 percent of the total variance. Distributions of the number of days exceeding 20 pphm and and of pphm-hours above 9 pphm within each source history category exhibited features very similar to those observed for the subregion average daily maximum concentrations. Those source history categories and subregions associated with high seasonal mean concentrations were also associated with large numbers of exceedances and high pphm-hour indices.

To develop a more rigorous and objective approach to episode classification, we used the subjective analysis of 1983-1984 data to formulate a series of numerical criteria that can be used to classify a day into one of eight source history categories on the basis of relative ozone concentrations and meteorological conditions. When these criteria were applied to data from 1985, reasonably good agreement was obtained between the subjectively and objectively determined categories. Most differences centered around the distinguishing features of Partial Southern Route and Southern Route days and the proper identification of Typical Pattern days. These results serve to verify that the subjective classification procedure is consistent and reproducible.

Having initially defined a set of source history categories on the basis of aerometric and meteorological conditions, we next attempted to identify combinations of purely meteorological conditions (i.e., meteorological "signatures") that could be used to uniquely determine the category a particular day belongs to even for days on which precursor emission patterns differ from those prevailing during the 1983-1984 time period. This step is necessary for the development of a consistent categorization scheme that can be applied to a long historical record. We attempted to identify meteorological signatures by growing a classification tree using the CART methodology. The resulting tree provides a decision rule for identifying the likely source history category of a particular day solely on the basis of meteorological conditions. Although the tree we developed classified 75 percent of the days in the 1983-1985 period correctly, the analysis failed to identify any significant combinations of meteorological conditions that were not already incorporated into the objective category definitions we developed. Thus, the CART results did not provide any significant new insights into the meteorological mechanisms associated with each source history category. Additional meteorological data will be needed if such relationships are to be identified and a more accurate classification procedure developed.

Although the source history categories we identified are most likely associated with fairly unique flow patterns, a certain degree of variability still exists among the days within each category with respect to the conduciveness of meteorological conditions on each day to ozone formation. Therefore, the relationship between ozone concentrations and meteorological conditions on any given day is dependent in part on the source history category and in part on other meteorological factors. As a first step towards understanding the latter relationship, we developed a linear regression model for the daily maximum ozone concentration in each subregion using meteorological parameters as predictor variables for the Eddy and Typical source history categories. Our results showed that temperature variables play the most significant role in determining ozone levels within each category: Warmer days are nearly always associated with higher concentrations, although the exact temperature variable that is most closely related to ozone varies from one subregion to another and one source history category to another. In the coastal and metropolitan areas, the association of ozone concentrations with meteorological conditions under the Eddy Pattern is quite weak, whereas in other areas under Eddy conditions and in all areas under Typical Pattern conditions, strong relationships were observed.

CONCLUSIONS

Results of the pilot study summarized above suggest that we may have succeeded in identifying at least four groups of days that represent distinct sets of source history characteristics. Each of these source history categories appears to be associated with a distinct spatial distribution of both relative and absolute ozone concentrations and with distinct meteorological features. Based on these findings, we can tentatively conclude that the mechanisms leading to the afternoon ozone peak in each subregion (emission contributions from specific sources, mixing, transport and chemical transformation) are basically the same for days within the same category. Only the details (in particular those details influenced by temperature variations) vary from day to day. Therefore, days within each of the four distinct categories we have identified should be representative of one another with respect to the response of ozone concentrations on these days to a given set of emission control measures. Furthermore, meteorologically adjusted year-to-year ozone trends can be obtained by considering only those days in each year that belong to the same category (making suitable corrections to account for the remaining temperature effects).

Clearly, the evidence on which the above conclusions are based is largely circumstantial and further verification is required. In the second phase of our study, we attempted to further explore the features of, and differences between, the source history categories identified in the pilot study by examining daily ozone cycles and air parcel trajectories. We then developed a procedure for identifying two well-defined source history categories on the basis of meteorological data only and applied the results to the problem of meteorological adjustment of ozone trends. Details are provided in the following sections.

PART II: ADDITIONAL ANALYSES

5 FURTHER ANALYSES OF SOURCE HISTORY CATEGORIES

Results of the pilot study presented in the previous section indicate that at least some of the eight source history categories originally identified by Zeldin can be shown to have been successful in isolating distinct source history relationships. However, further substantiation of this finding is needed. Additional analyses are also needed which will allow us to better understand the unique nature of each category with respect to temporal and spatial concentration distributions and meteorological scenarios. In this section, we describe two additional analyses designed to further illuminate the nature of Zeldin's source history categories: An analysis of the diurnal ozone cycle associated with each category and an analysis of air parcel trajectories on days falling in different categories.

DIURNAL PROFILE ANALYSIS

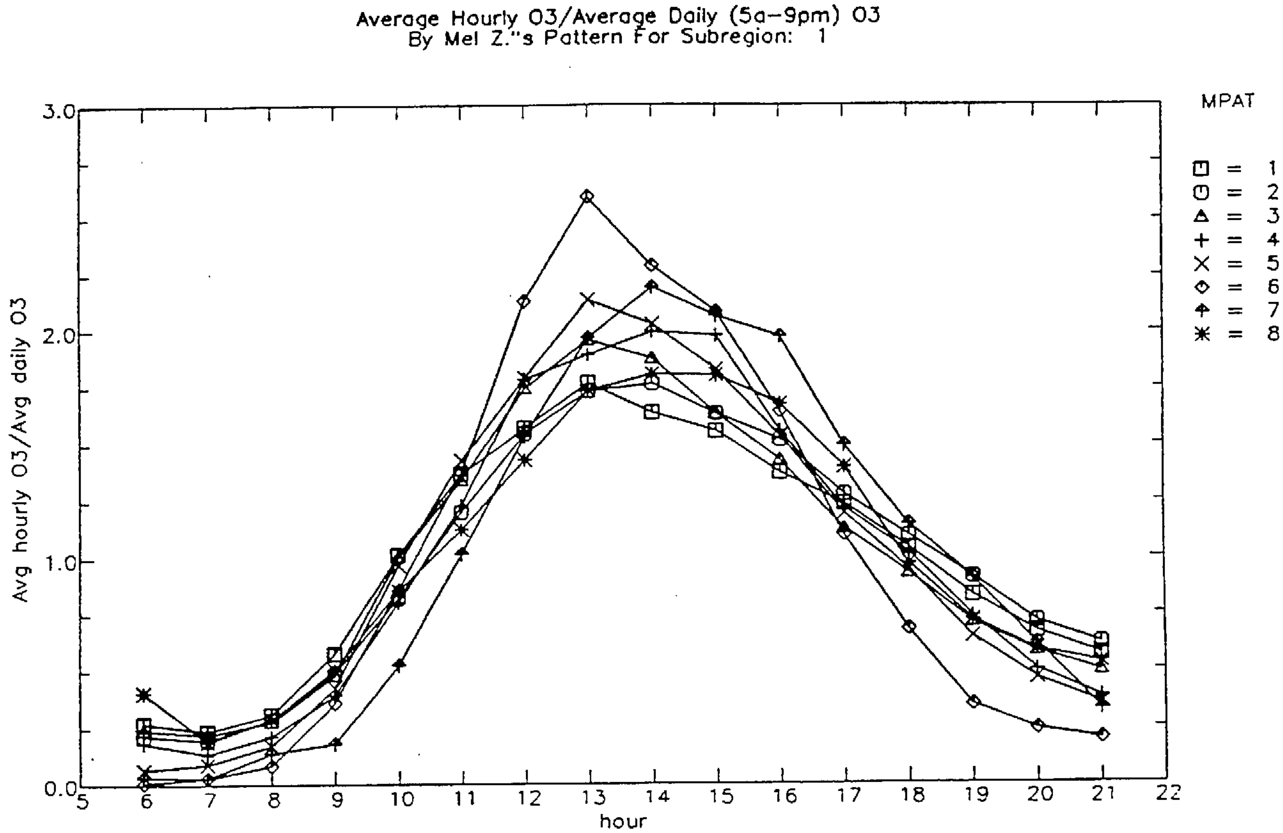
In this section we analyze differences between source history categories in the diurnal profiles of ozone concentrations. If each source history category actually describes a unique set of source-receptor relationships, then diurnal ozone profiles for most days in a given category are likely to exhibit a unique set of characteristics that differentiate these profiles from those observed on days associated with other source history categories. To test this hypothesis, we compared diurnal ozone profiles for days grouped by Zeldin's source history categories. To facilitate the comparison, normalized profiles were calculated as follows:

Subregion averages were calculated for each hourly average ozone reading.

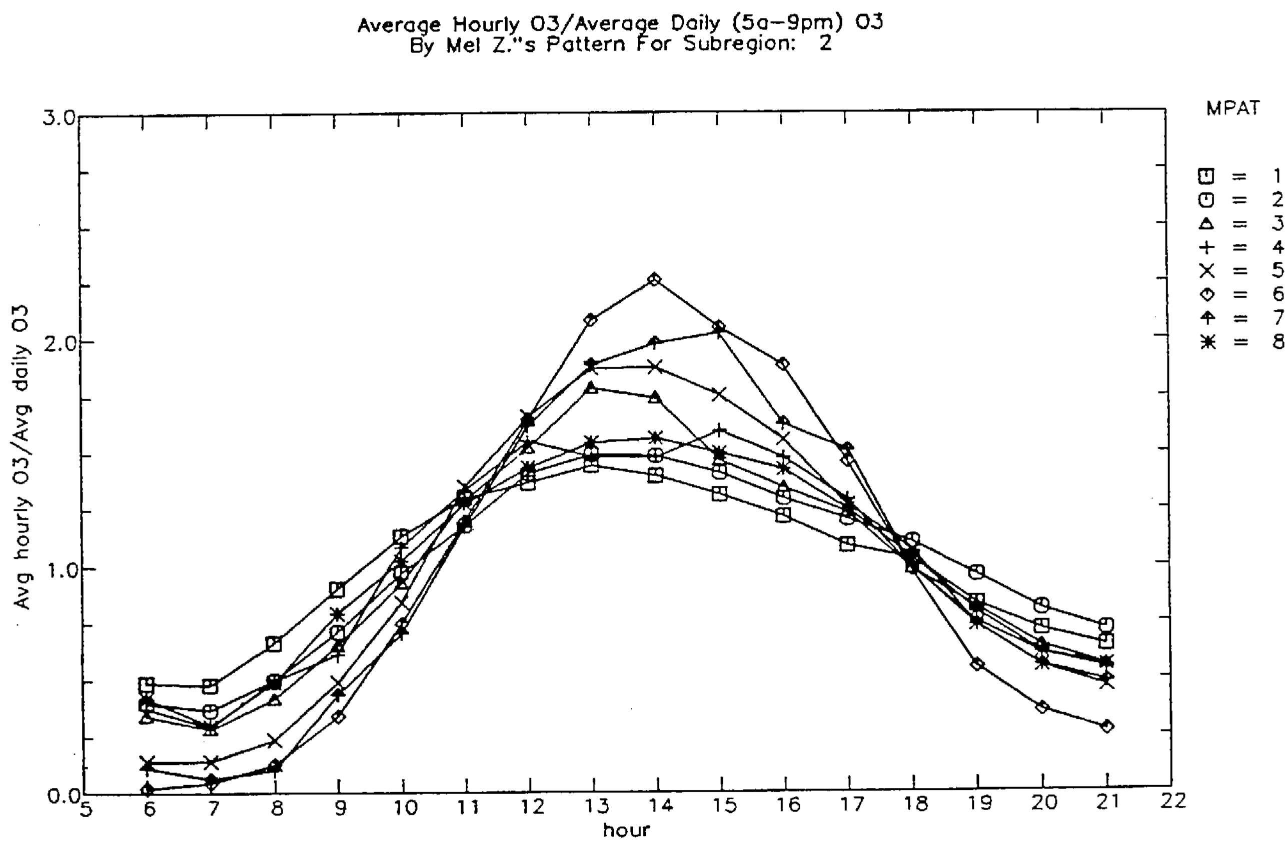
The resulting subregion diurnal profiles were then normalized by the subregion daily mean concentration.

The normalized subregion profiles were then averaged across days in each source history pattern.

The above calculations were performed for the hours between 6:00 a.m. and 9:00 p.m., LST and the resulting average profiles plotted for each subregion as shown in Figure 5-1. Examination of these figures reveals several interesting features:

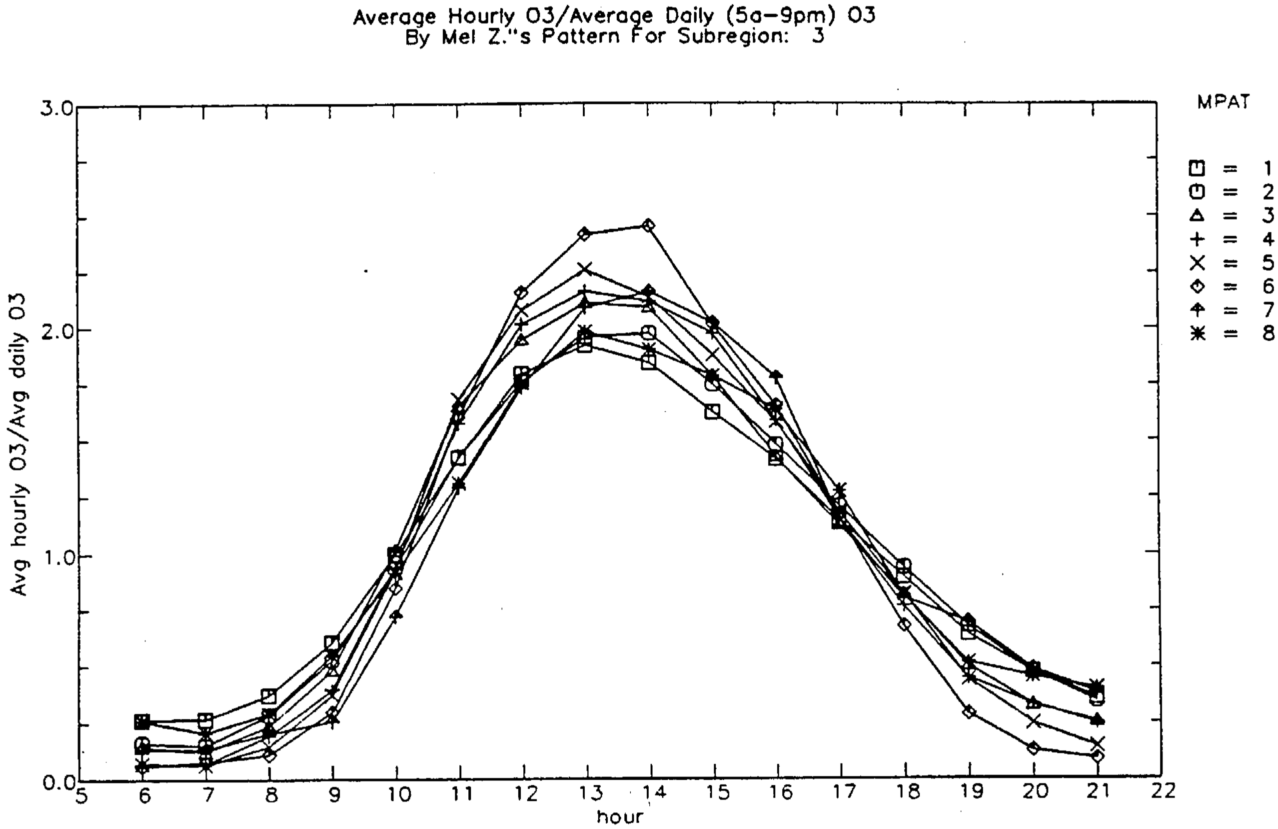


North Coast

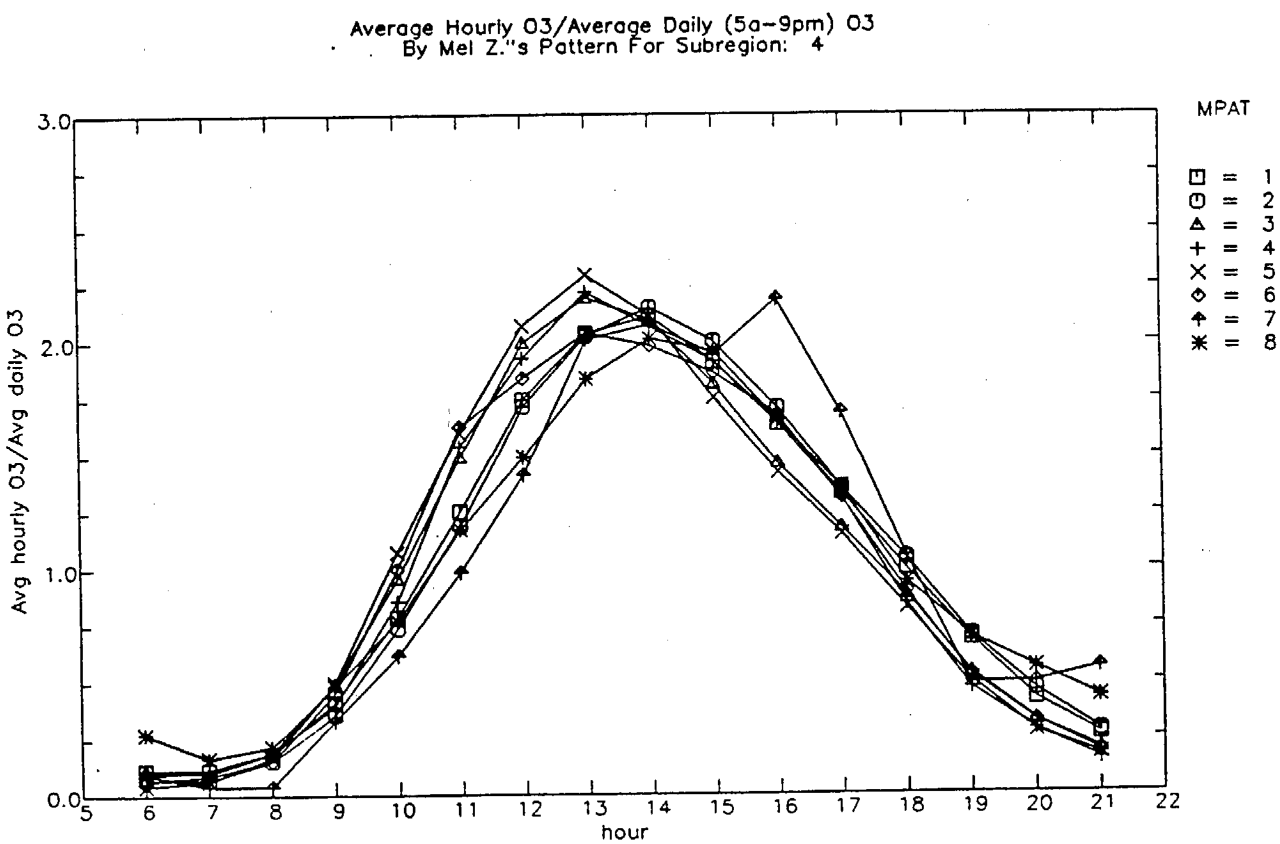


South Coast

FIGURE 5-1. Diurnal variation of normalized hourly ozone concentrations. Categories (MPATs) are defined in Section 3.



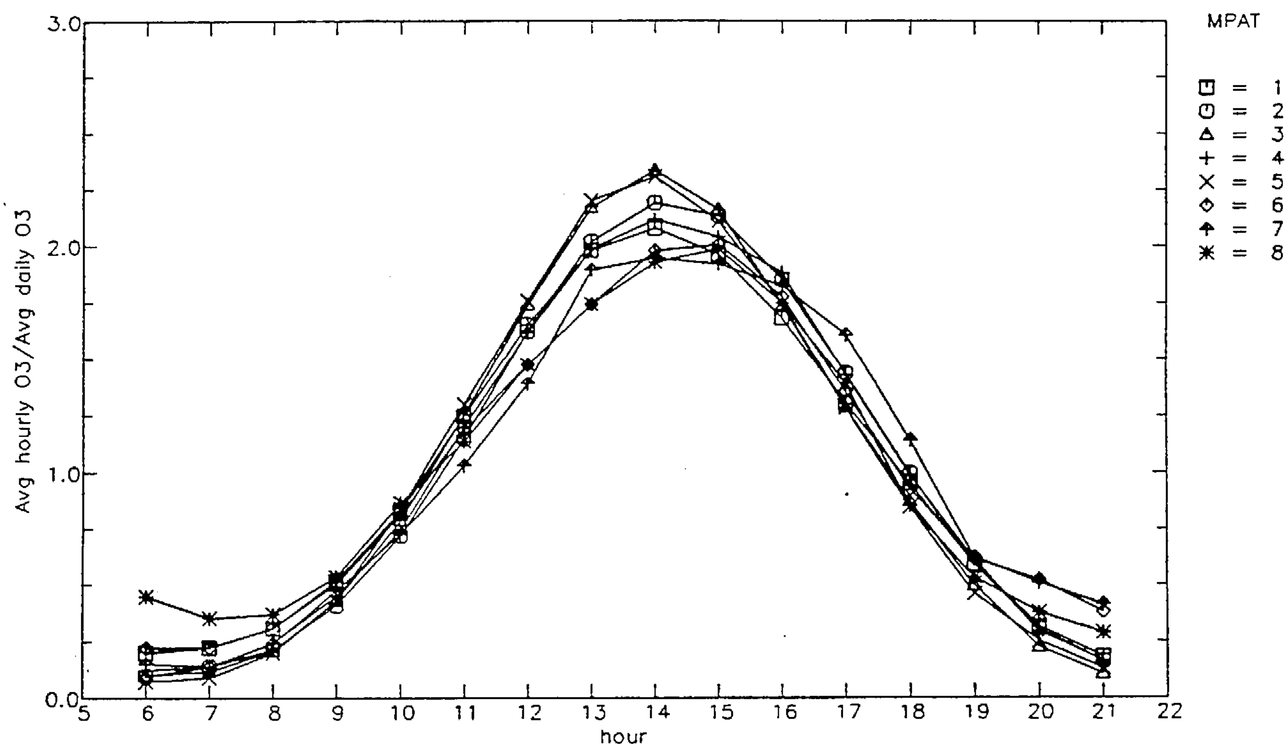
Metropolitan



San Fernando Valley

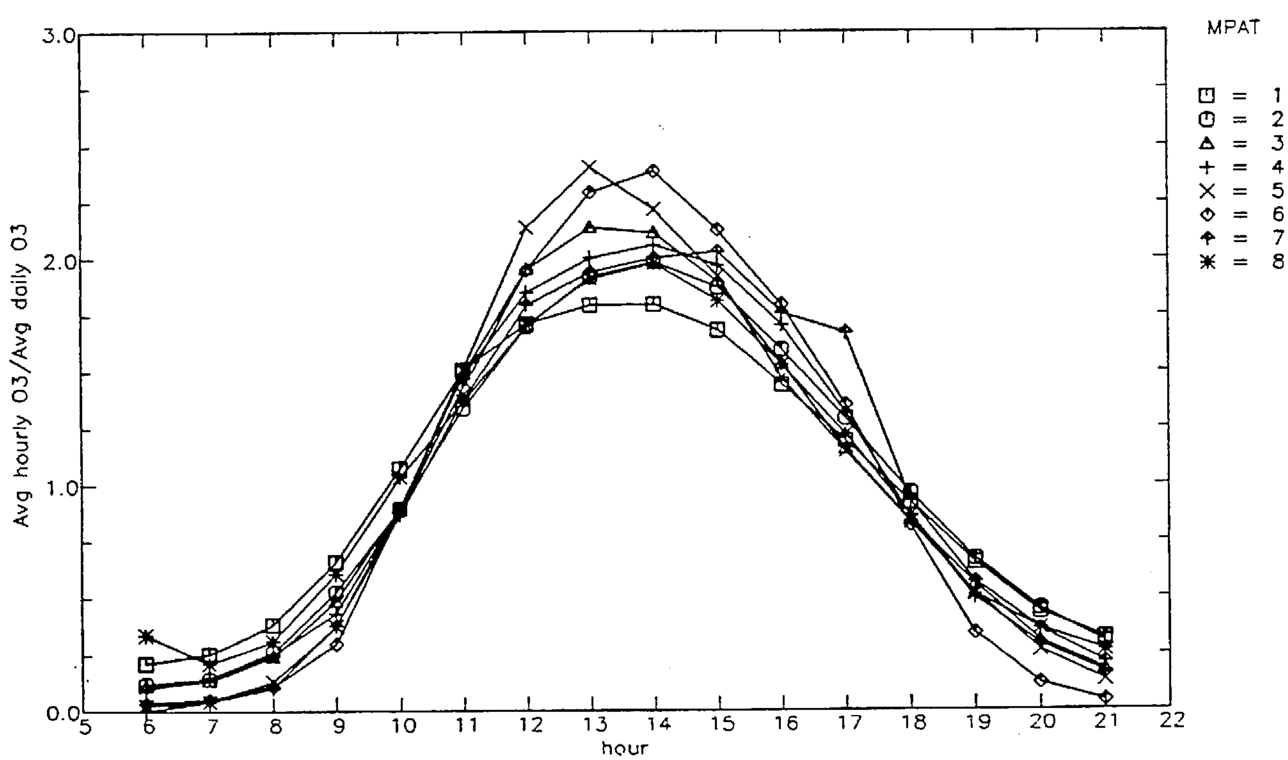
FIGURE 5-1. Continued.

Average Hourly O3/Average Daily (5a-9pm) O3
By Mel Z."s Pattern For Subregion: 5



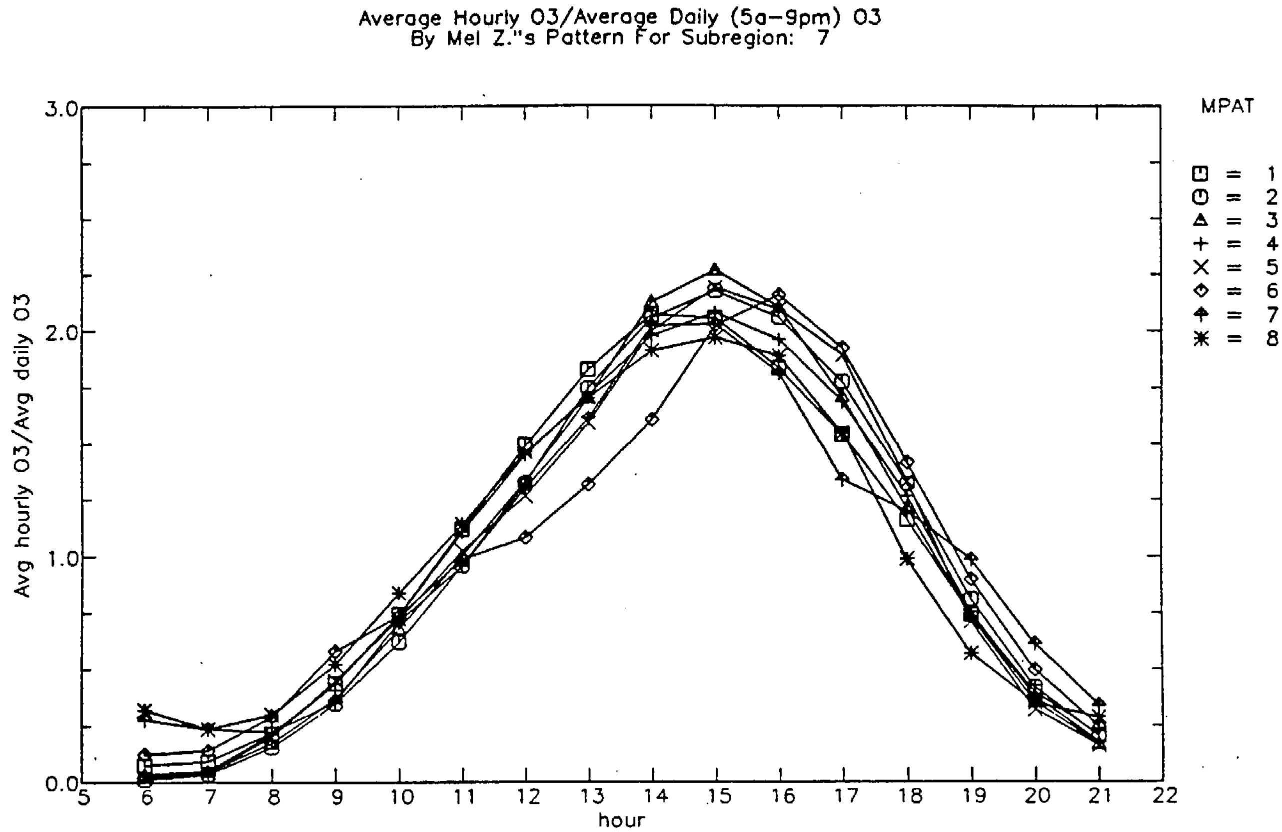
San Gabriel Valley

Average Hourly O3/Average Daily (5a-9pm) O3
By Mel Z."s Pattern For Subregion: 6

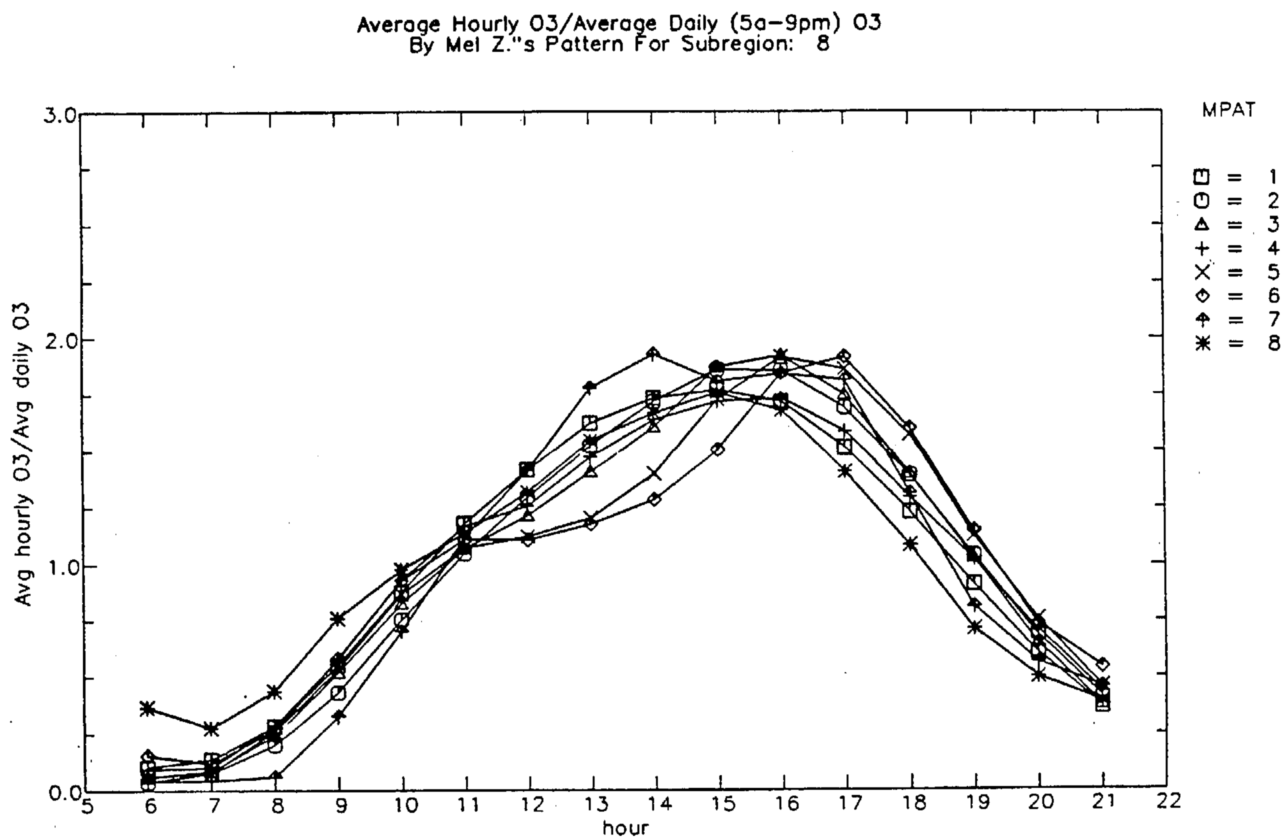


Inland Metro.

FIGURE 5-1. Continued.



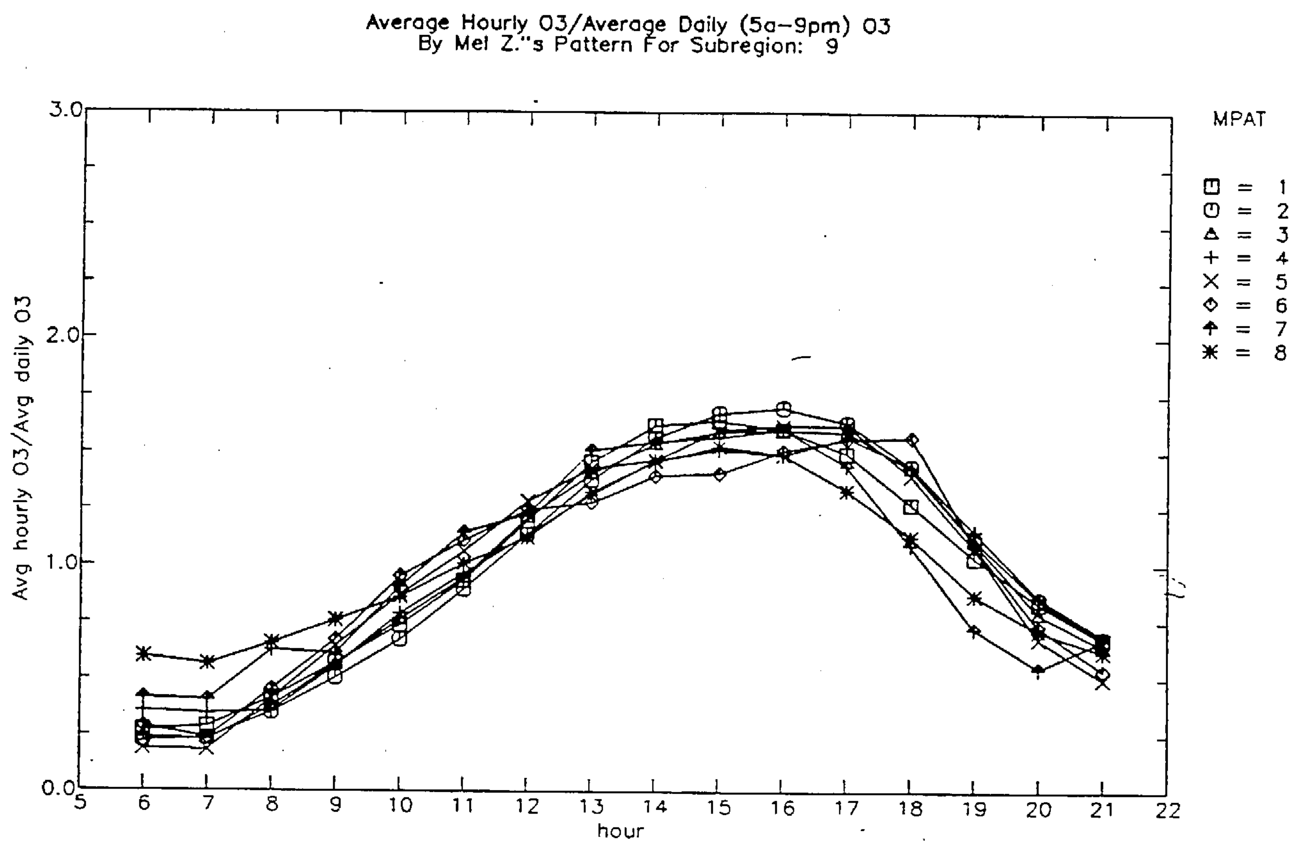
Inland Foothill



Inland Valley

FIGURE 5-1. Continued.

90028



Mountain

FIGURE 5-1. Concluded.

Certain source history categories are associated with diurnal profiles that are more "peaked" (i.e., high concentrations are limited to a relatively narrow time interval during the middle of the day) than those for most other categories. For example, in the North and South Coastal and Metropolitan subregions, the normalized profile for the Southern Route category has a narrower, taller peak than do profiles for the other categories. In the Inland Metro subregion, profiles for both the Southern Route and Partial Southern Route categories are more "peaked" than those for other categories. By way of contrast, the profile for Eddy days (which are associated with the lowest ozone concentrations in this subregion as indicated in Figure 3-33(f) of the pilot study) is relatively flat.

With the exception of the Inland Valley subregions, the time of the daily ozone maximum differs from one category to the next by at most one hour. This difference, though small, may be significant given the relatively large number of observations which have been averaged over to obtain the curves in Figure 5-1.

In the Inland Valley (and to some extent the Inland Foothill) subregion, the Partial Southern Route and Southern Route profiles exhibit a sharp break in the mid-morning ozone buildup beginning at 1100 PST, which delays the occurrence of the daily maximum to 1600 PST (1700 PST for Southern Route days). This feature clearly separates the Partial Southern and Southern Route profiles from those for the other categories. On days in these categories, transport of ozone and precursors from the emission source regions to the west is diminished and delayed relative to days in other categories. Thus, ozone concentrations are flat during the midday period after precursors from the morning rush hour have "cooked" to a point where little additional ozone is being produced. (Since sources in this portion of the basin are known to be characterized by high HC/NO_x ratios, the midday fall-off in ozone production is most likely a result of insufficient NO_x concentrations.) Ozone concentrations start to build again during the afternoon as a result of transport of ozone and fresh precursors from the west.

We performed an analysis to test the statistical significance of the differences in diurnal ozone patterns between source history categories noted above. A linear model was developed that approximates the log of the hourly ozone concentrations as a function of a group effect (the source history category), a time effect (the hour of the day) and the interaction between the group and time effects. This model was developed using the SAS General Linear Models (GLM) procedure (SAS Institute Inc., 1990). Under the assumptions that data for one day in a group are independent of those for any other and that the normalized hourly values that make up each diurnal profile follow a multivariate normal distribution, the null hypothesis that the corresponding hourly values in different groups are equal was rejected at the 99.9 percent confidence level for all nine subregions. In other words, we can state with a high degree of confidence that normalized diurnal profiles are significantly different from one source history category to the next at each subregion. The particular repeated measures analysis of variance test used to arrive at this conclusion does not require any assumptions concerning the equality of variances of each normalized hourly value or of covariances between hourly values on the same day.

Based on the results presented above, it appears that at least some of Zeldin's source history categories are associated with clearly unique normalized diurnal profiles. From this result it is reasonable to infer that at least some of the categories do indeed represent unique combinations of source-receptor relationships.

BACK TRAJECTORY ANALYSIS

One way to verify the uniqueness of Zeldin's source history categories and to gain a better understanding of the nature of the flow patterns they represent is to compare typical air parcel trajectories on days selected from different categories. We calculated back trajectories beginning at the time of the afternoon ozone maximum at several monitoring sites for groups of days selected from five of Zeldin's categories. Back trajectories were not computed for category #4 (Typical Pattern - Eddy Winds) and category #7 (Offshore) since very few days fell into these categories (see Table 3-11). In addition, trajectories were not computed for category #8 (Low Ozone) since these days are generally not of interest to air quality managers. Monitoring sites selected for the analysis are Reseda, Pasadena, Azusa, Pico Rivera and San Bernardino. These sites are located in those portions of the basin where high ozone concentrations are most likely to be found on any given day.

Trajectories were calculated using hourly SCAQMD surface wind data described in Section 2. These observations were interpolated onto a 175 km by 90 km grid (5 x 5 km grid cells) using a distance-weighted $1/r^2$ interpolation followed by four passes through a 5-point smoothing filter (Douglas and Kessler, 1988). No attempt was made to limit the vertical velocities implied by the interpolated surface wind field, but a visual check of fields calculated for a few days indicated that the fields are generally smooth and without unreasonable divergence, given that only limited surface data were available and that terrain effects were not considered. A typical example of the station wind data and resulting interpolated wind field is presented in Figures 5-2 and 5-3.

Back trajectories were calculated by interpolating the analyzed wind field to the monitor location, advecting an imaginary air parcel backwards for one time step (equal to 15 minutes) and computing the new parcel position. This process is repeated for the desired number of time steps, using the analyzed wind field for the appropriate hour at each step.

Days were selected for the back trajectory calculations as follows: All consecutive two-day sequences during the pilot study period for which both days belong to the same source history category were identified. Only one sequence longer than two days was found: The three-day period 8/21/84 - 8/23/84 in the Typical category.

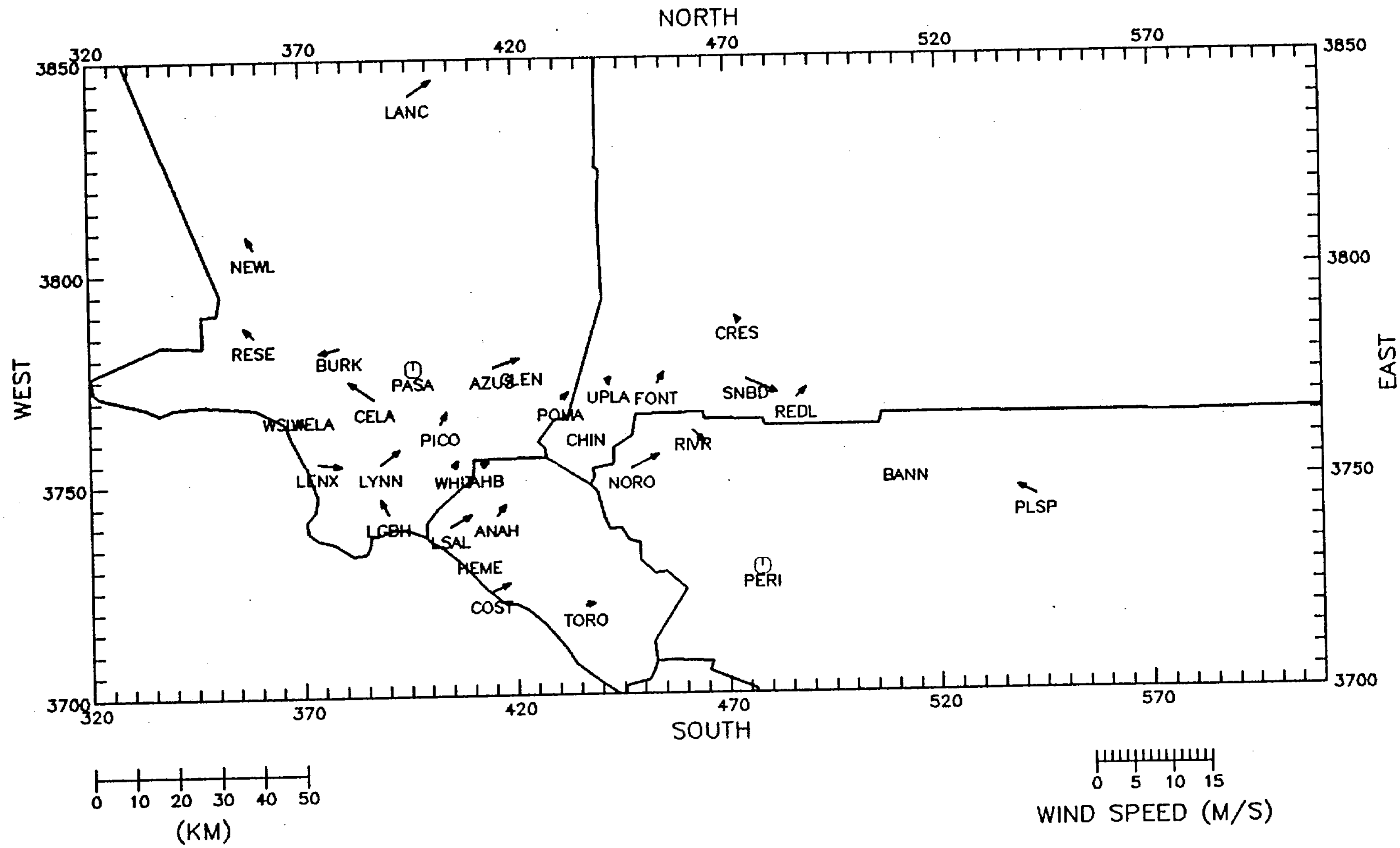
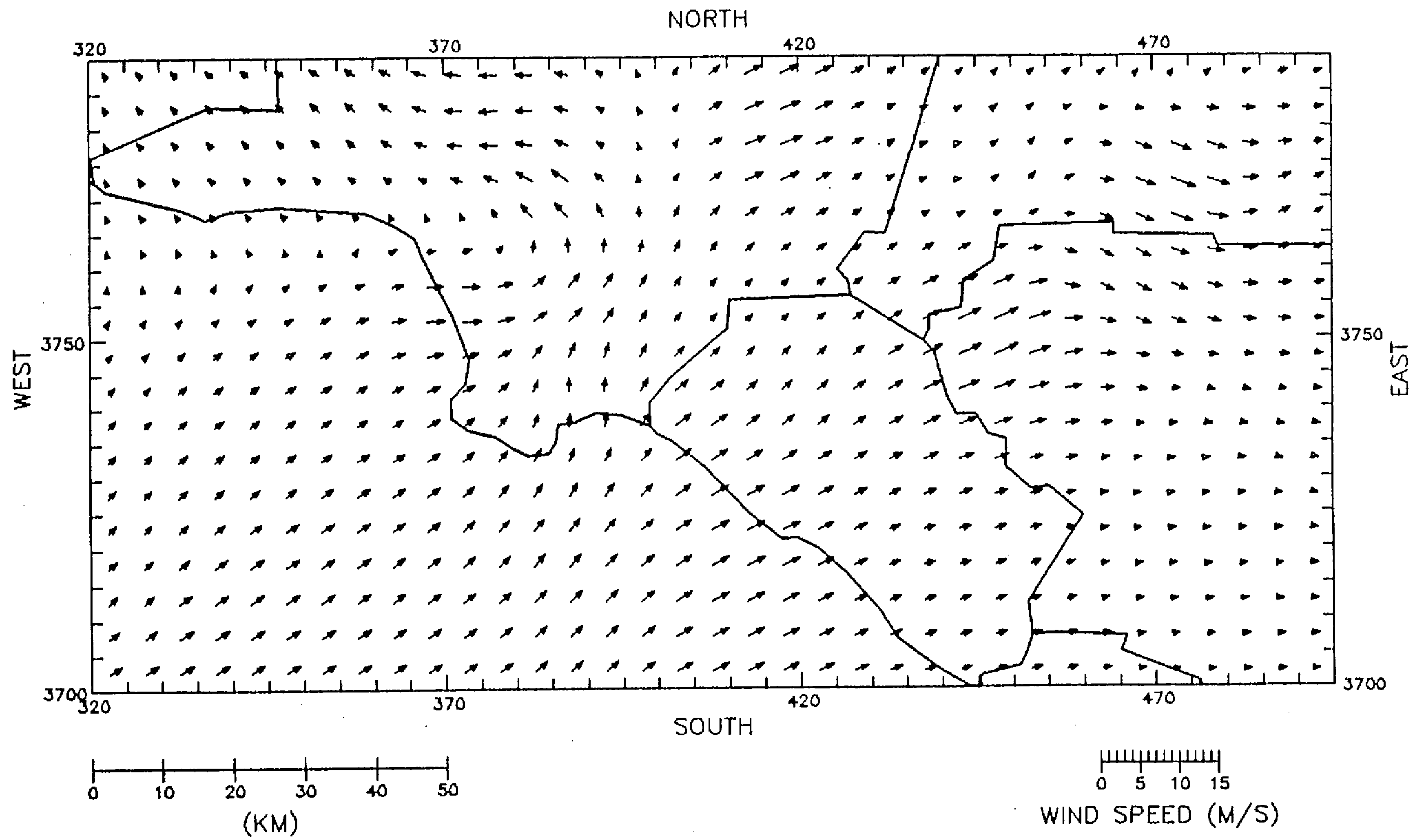


FIGURE 5-2. SOCAB wind observations, 11 July 1984 1200 PST. Solid lines are county boundaries.

90028



SCAQMD SURFACE WINDS 1 (10M)

FIGURE 5-3. SOCAB gridded wind field from station data interpolation, 11 July 1984, 1200 PST. Solid lines are county boundaries.

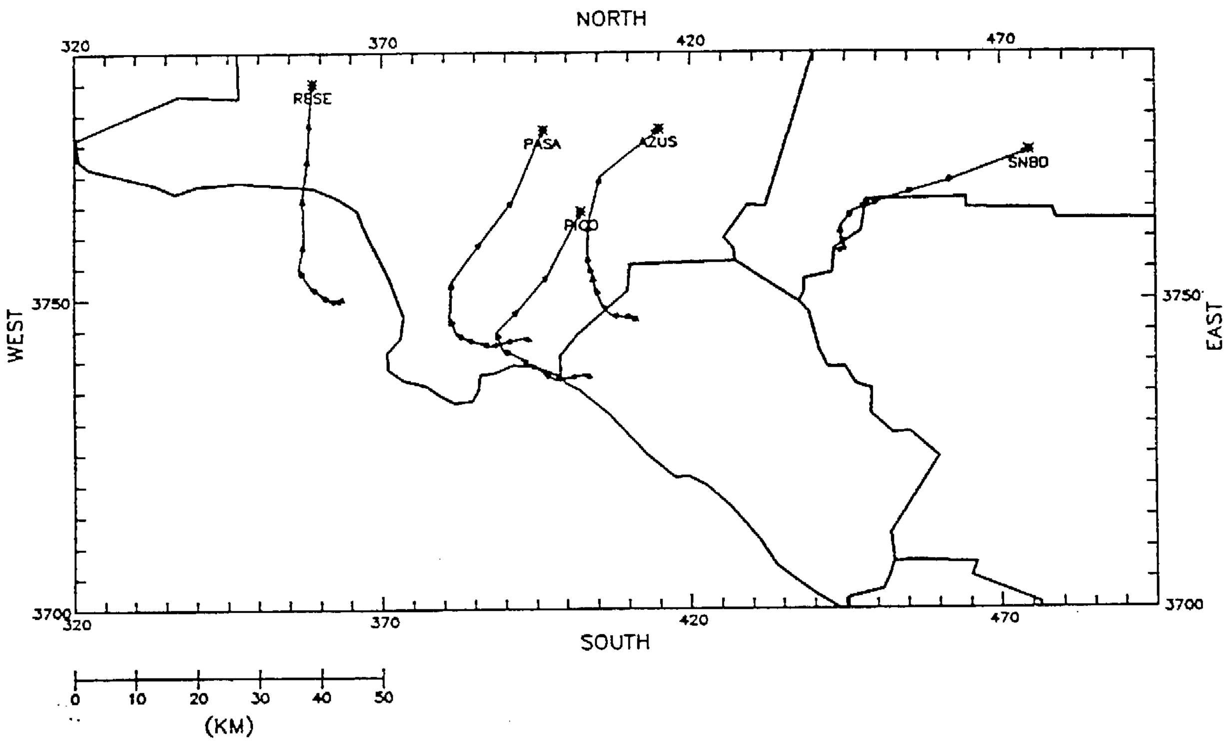
90028

The second (or third) day of each two- or three-day sequence was selected for the trajectory analysis. These days are thought to be more likely to exhibit the particular characteristics of each category since any transient effects resulting from a change in category will have had time to dissipate. This procedure resulted in the selection of 8 Eddy, 5 Partial Eddy, 7 Typical, 2 Partial Southern Route, and 1 Southern Route days. To provide a more representative sample, three additional Partial Southern Route and four additional Southern Route days were selected.

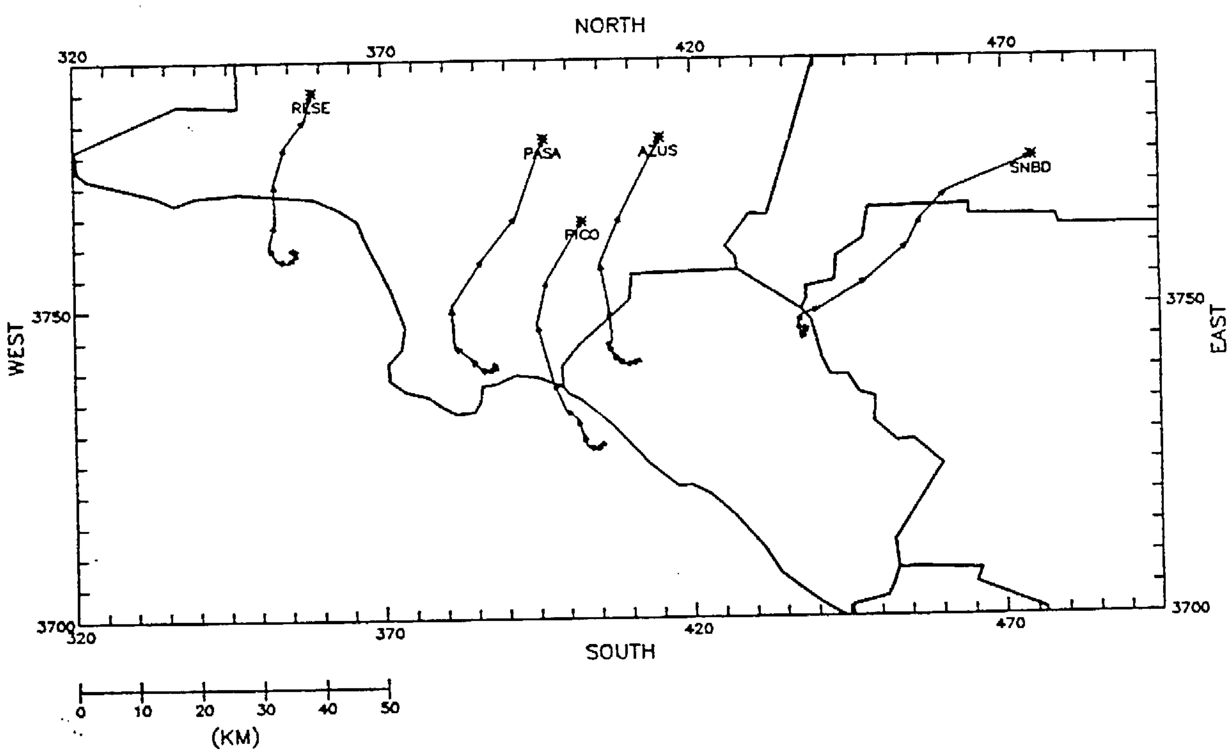
For each selected day, the time of the ozone maximum at the monitor with the latest afternoon ozone peak was used as the trajectory ending time. Trajectories were calculated backwards from this time until 5:00 a.m. on the morning of the same day. A separate trajectory was calculated for each monitoring site.

Results of the back trajectory calculations are presented in Figure 5-4 (for Eddy days), Figure 5-5 (Partial Eddy days), Figure 5-6 (Typical days), Figure 5-7 (Partial Southern Route days), and Figure 5-8 (Southern Route days). Along each trajectory in these figures, the arrow tips indicate the location of the air parcel at successive one-hour intervals. The date and the arrival time of the parcels at their respective monitoring sites are indicated in the lower left-hand corner of each plot. A review of Figures 5-4 to 5-8 shows that

> Most of the trajectories on Eddy days show a shift in wind direction during the day from east or southeast in the mornings through south to south or southwest in the afternoons. The wind shift occurred very early in the morning on 6/5/85 while trajectories for 5/30/85 are complex and do not follow this pattern. Of all the source histories, trajectories on Eddy days are the most consistent from day to day. Trajectories ending at Pasadena and Pico Rivera usually (but not always) originate in the Long Beach area while the Azusa trajectory usually originates a little further to the northeast. Reseda trajectories are usually shown as originating to the south over Santa Monica Bay, but this is most likely not realistic since the intervening Santa Monica mountains, which are not accounted for in the wind field analysis, would block such a northerly flow. This problem appears to have been exacerbated by a large amount of missing wind data at the Reseda monitor. Trajectories ending at the San Bernardino monitor usually originate in the Corona-Norco area at the mouth of the Santa Ana Canyon.
>
> With a few exceptions, trajectories on Partial Eddy days ending at the Pasadena, Azusa, and Pico Rivera monitors originate over the ocean waters to the southwest. The over-water portions of these trajectories must be viewed with some skepticism as no actual wind measurements were available offshore (the over-water portions of the gridded wind fields were derived by interpolating observations from mainland stations). As on most days, winds on Partial Eddy days are light and variable during the morning, becoming stronger and onshore as the day progresses. Partial Eddy trajectories do not show the effects of any consistent shift in wind direction during the morning hours. On

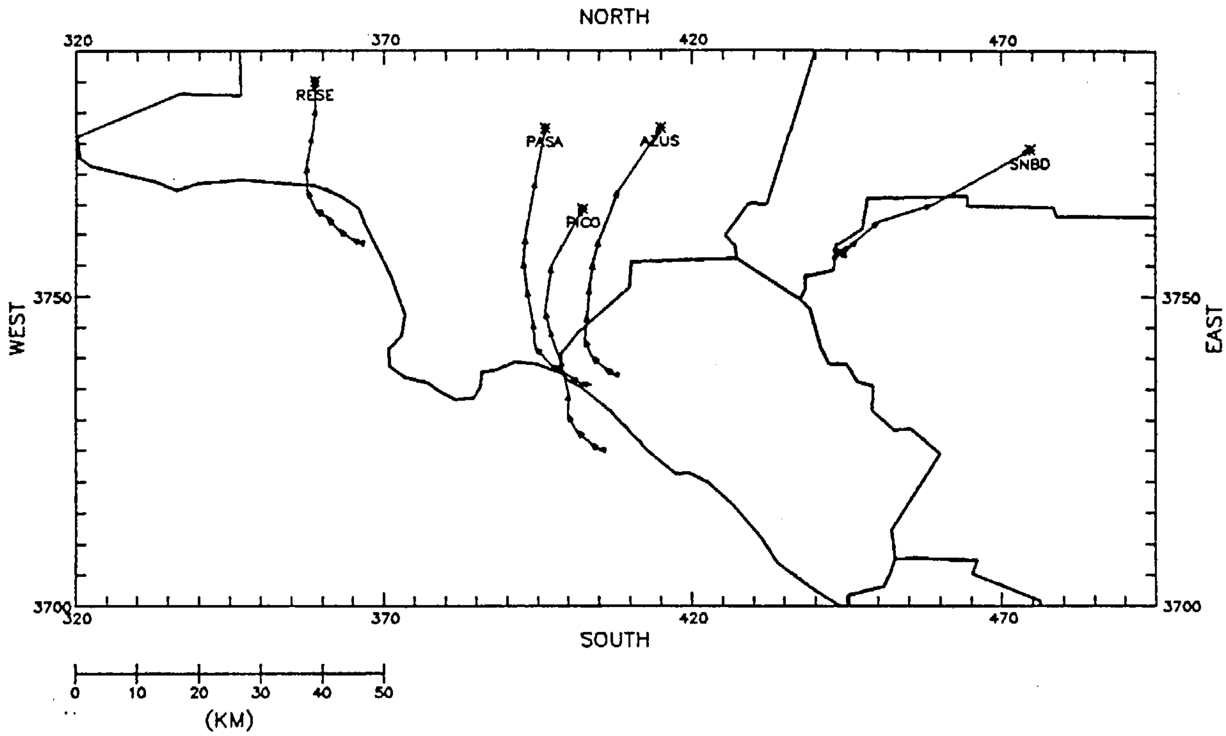


SCAQMD WIND SITES 1 (10M)
1500 PST 2MAY84

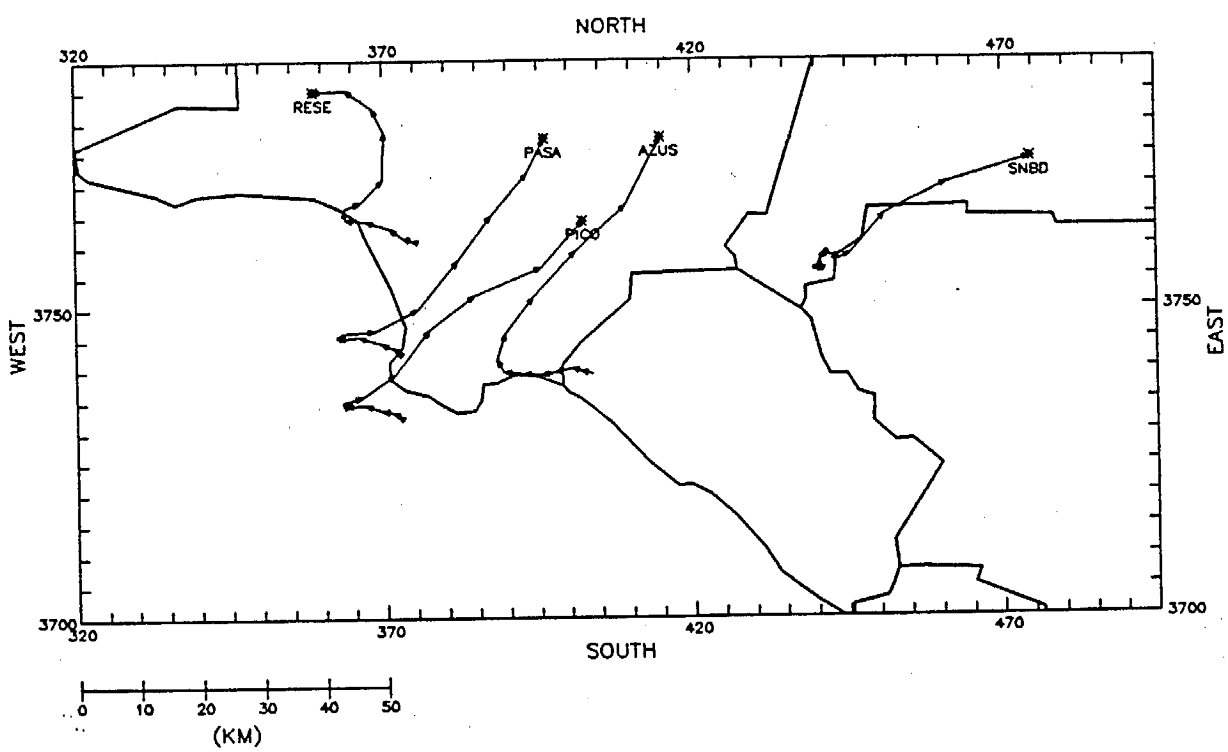


SCAQMD WIND SITES 1 (10M)
1500 PST 17MAY84

FIGURE 5-4. Trajectories for Eddy days. Date and time of arrival of air parcel at monitoring sites is indicated in the lower left-hand corner of each plot.



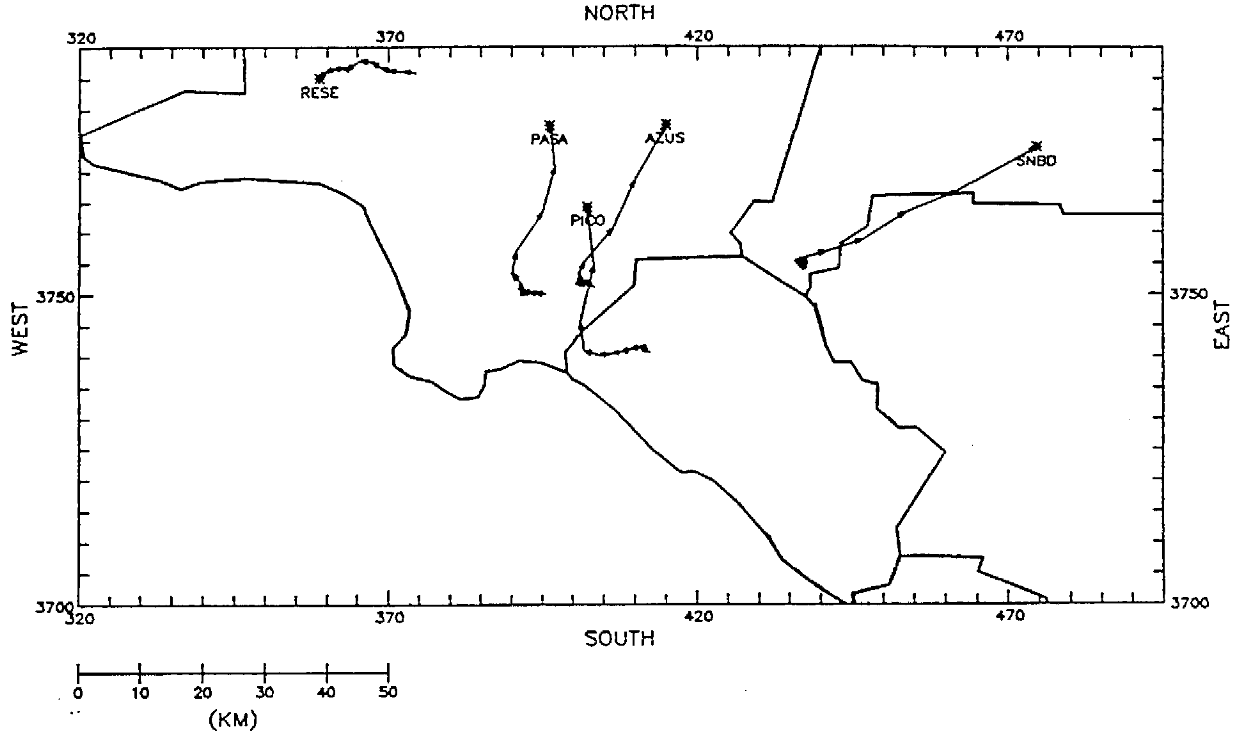
SCAQMD WIND SITES 1 (10M)
1400 PST 31MAY84



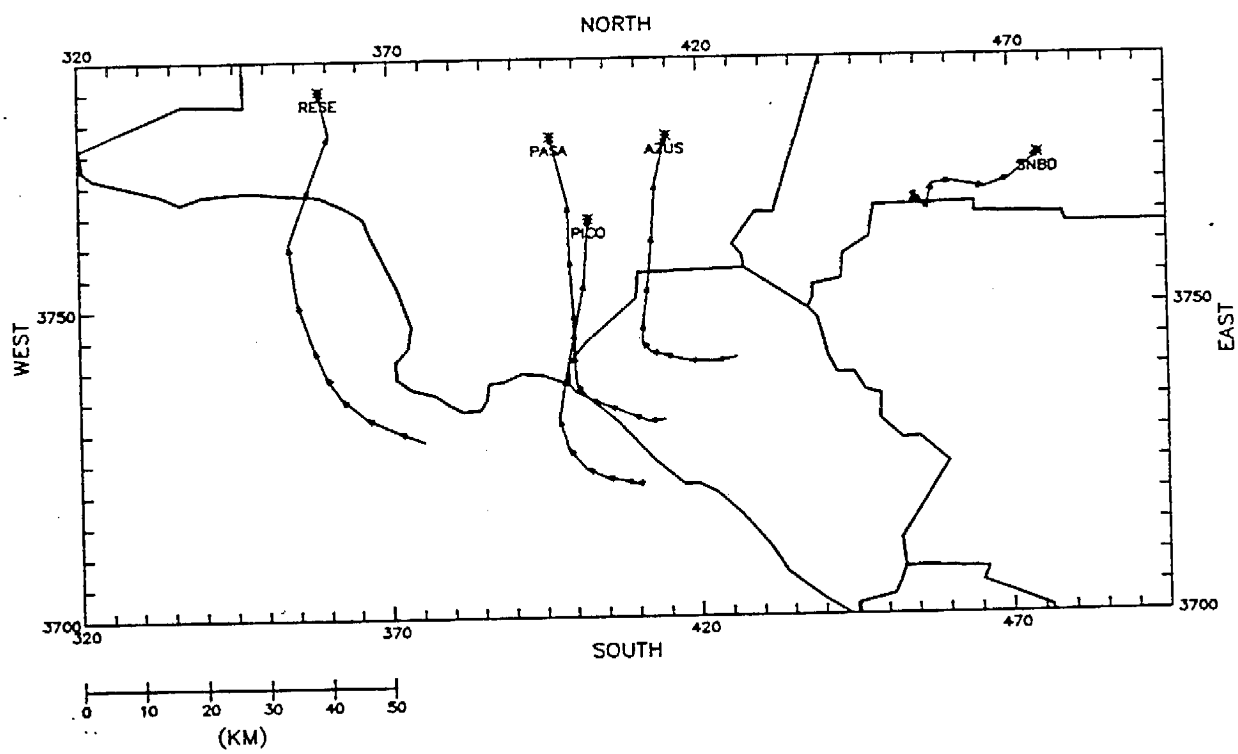
SCAQMD WIND SITES 1 (10M)
1600 PST 20JUN84

FIGURE 5-4. Continued.

90028

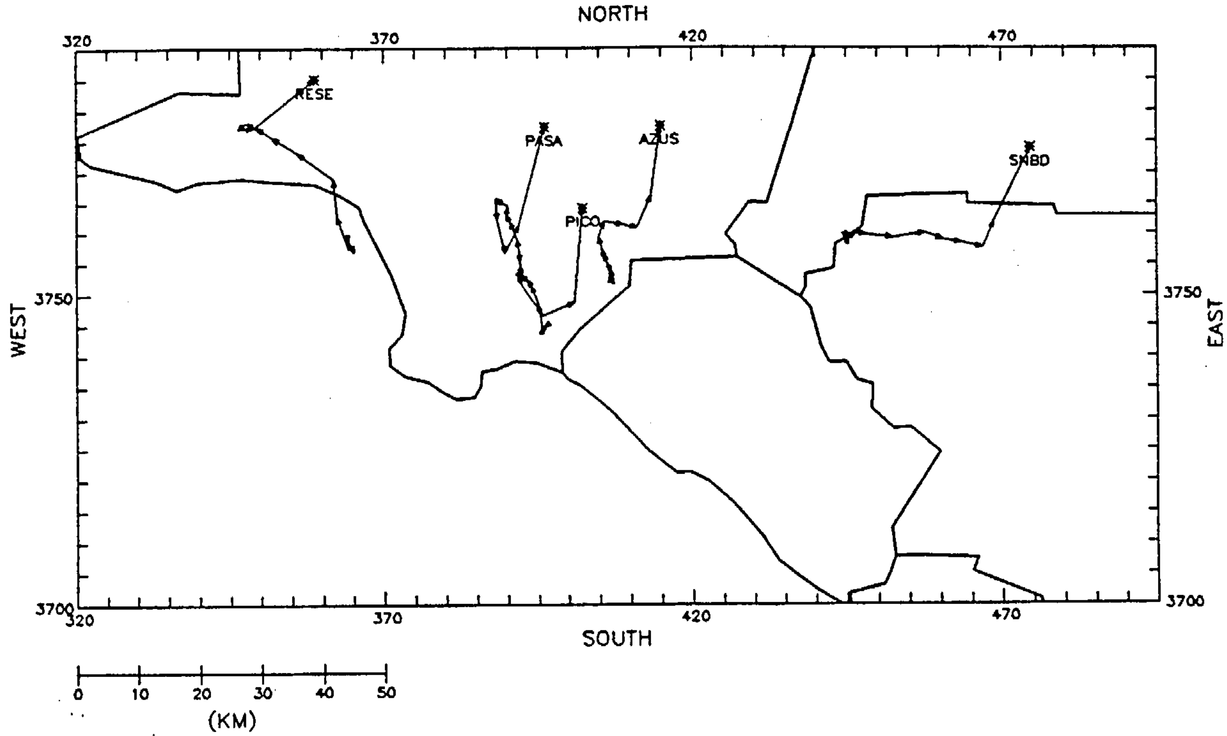


SCAQMD WIND SITES 1 (10M)
1400 PST 28JUN84

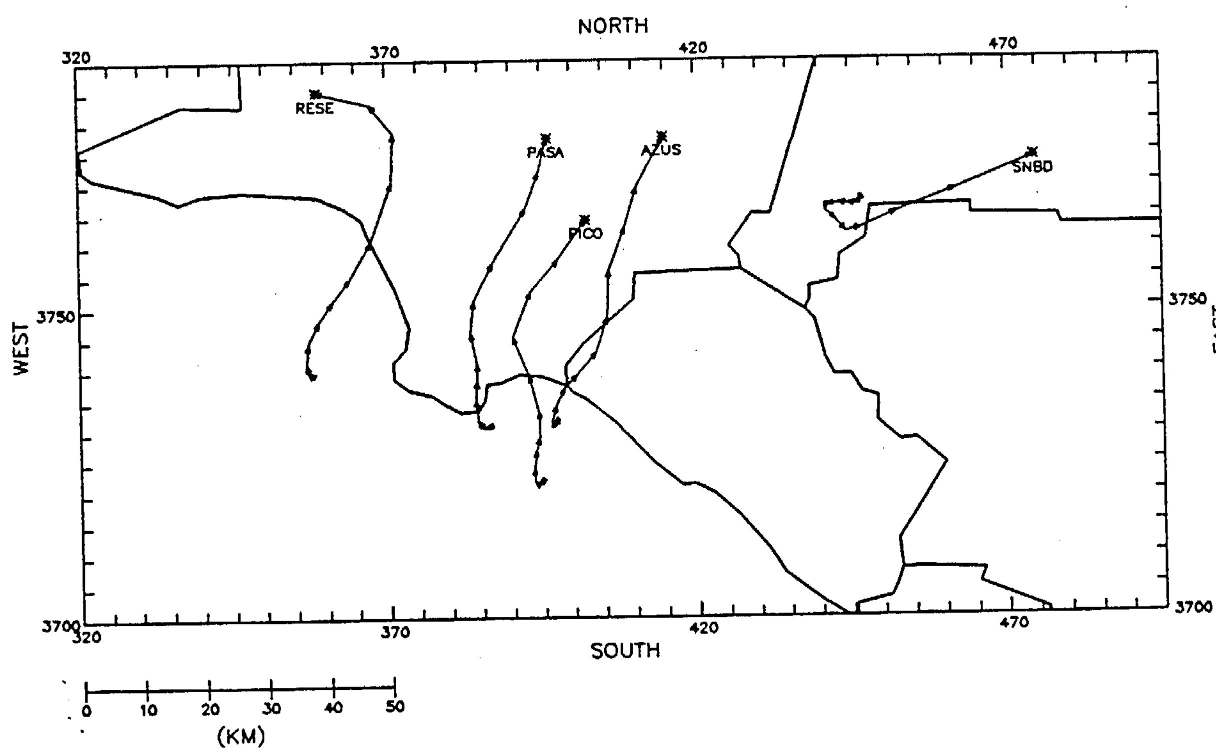


SCAQMD WIND SITES 1 (10M)
1400 PST 16MAY85

FIGURE 5-4. Continued.

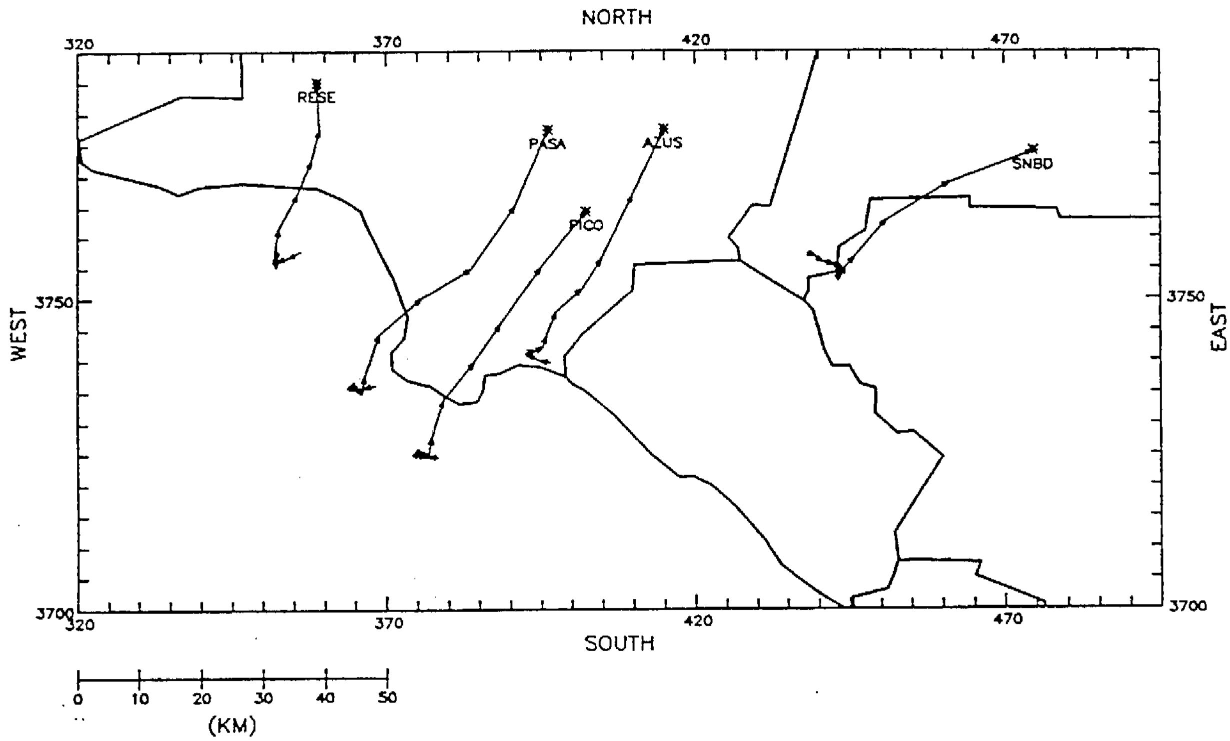


SCAQMD WIND SITES 1 (10M)
1600 PST 30MAY85

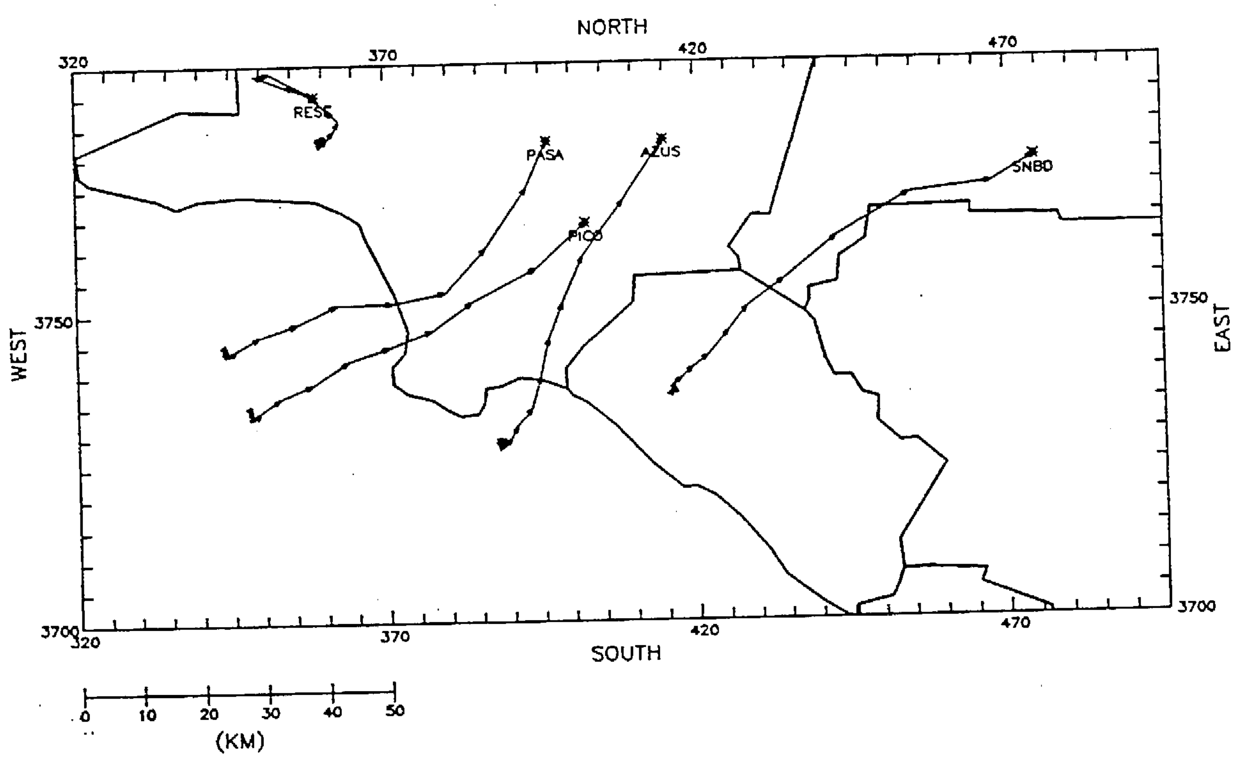


SCAQMD WIND SITES 1 (10M)
1600 PST 5JUN85

FIGURE 5-4. Concluded.

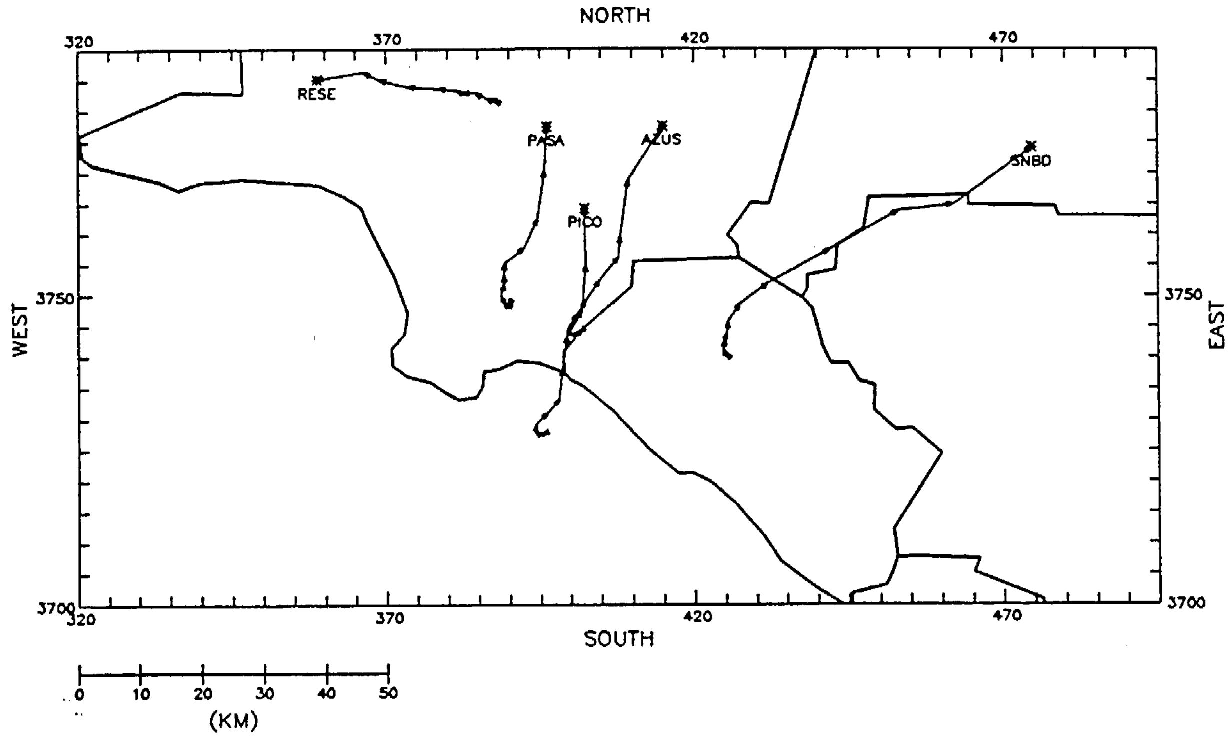


SCAQMD WIND SITES 1 (10M)
1500 PST 24MAY84

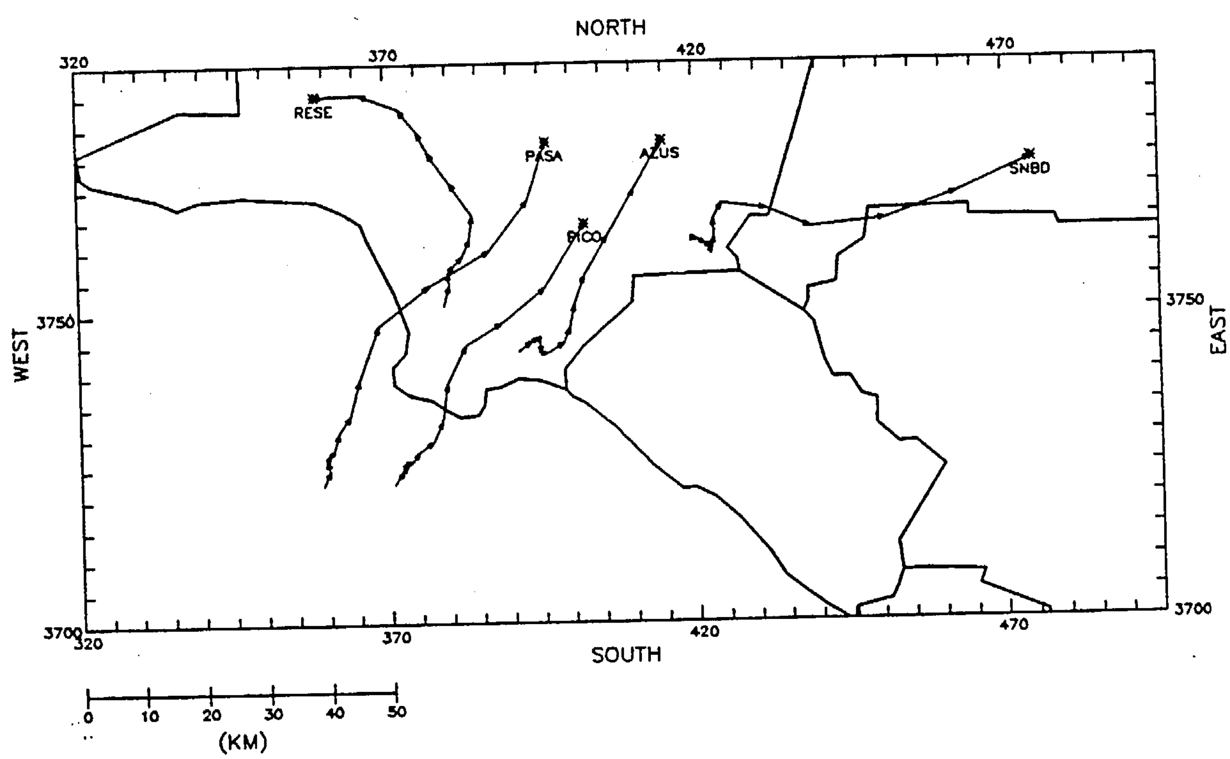


SCAQMD WIND SITES 1 (10M)
1700 PST 11JUL84

FIGURE 5-5. Trajectories for Partial Eddy days. Date and time of arrival of air parcel at monitoring sites is indicated in the lower left-hand corner of each plot.

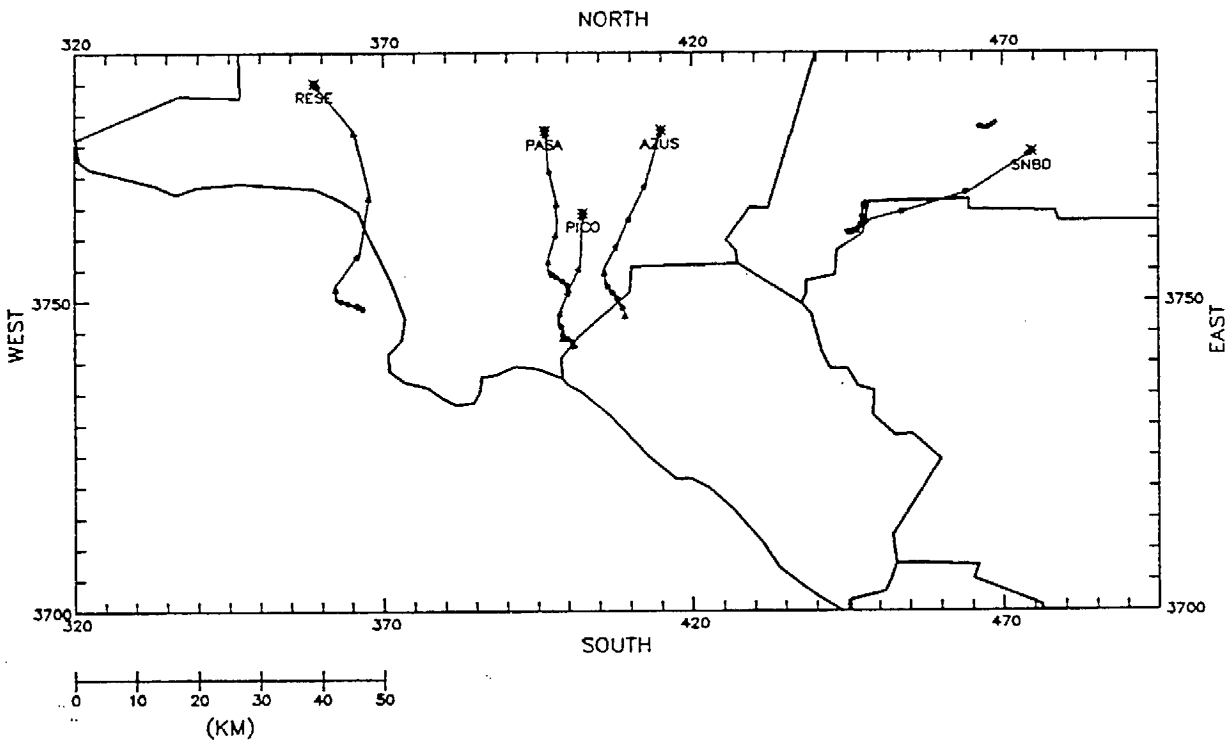


SCAQMD WIND SITES 1 (10M)
1500 PST 1AUG84



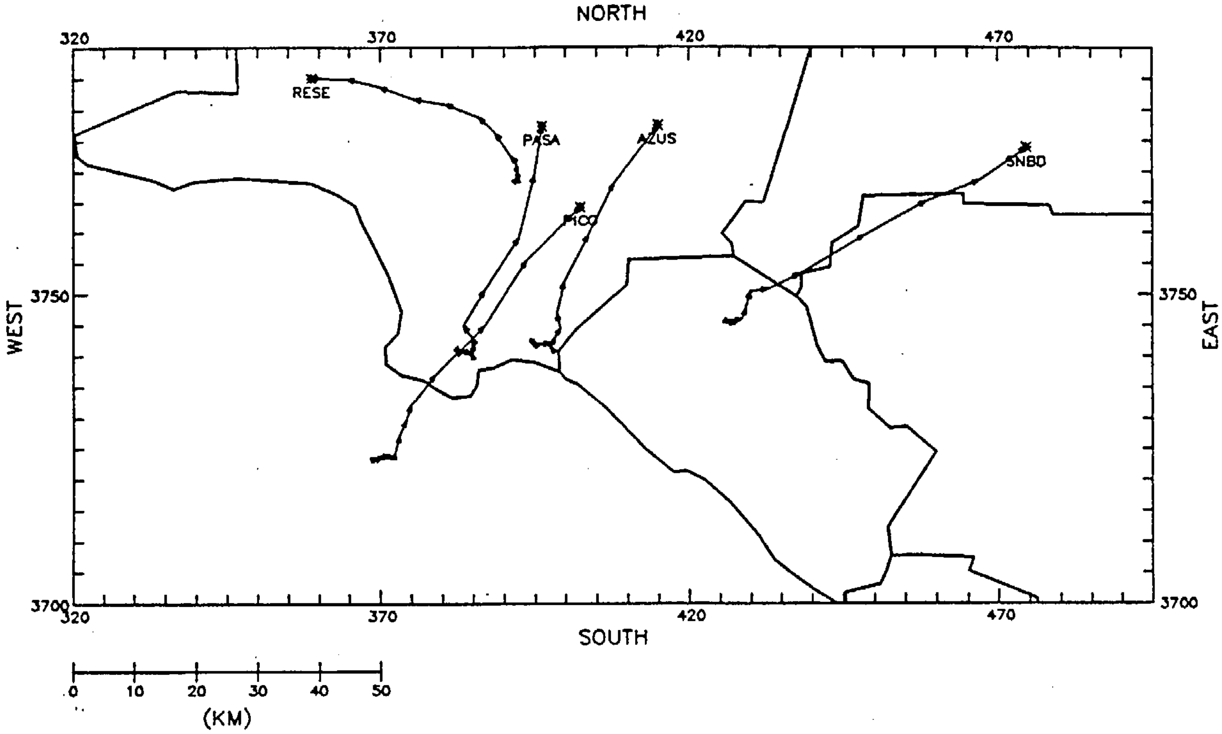
SCAQMD WIND SITES 1 (10M)
1600 PST 13JUN85

FIGURE 5-5. Continued.

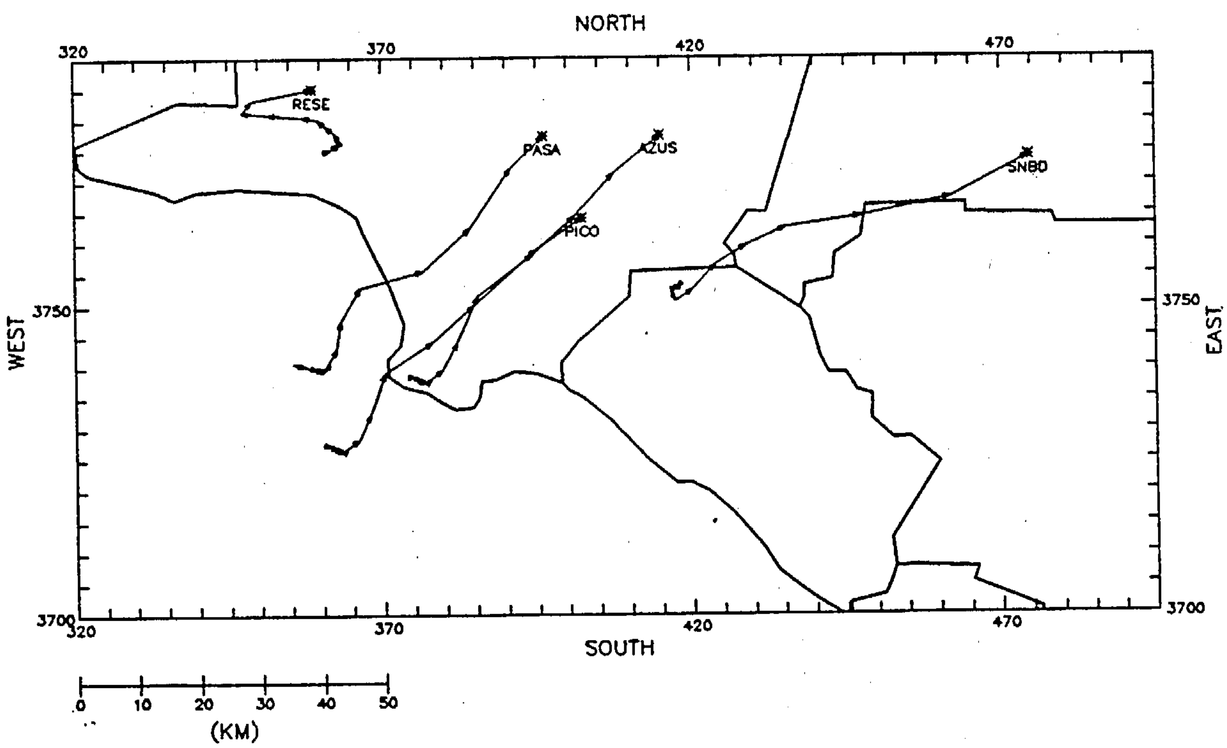


SCAQMD WIND SITES 1 (10M)
1400 PST 19JUN85

FIGURE 5-5. Concluded.

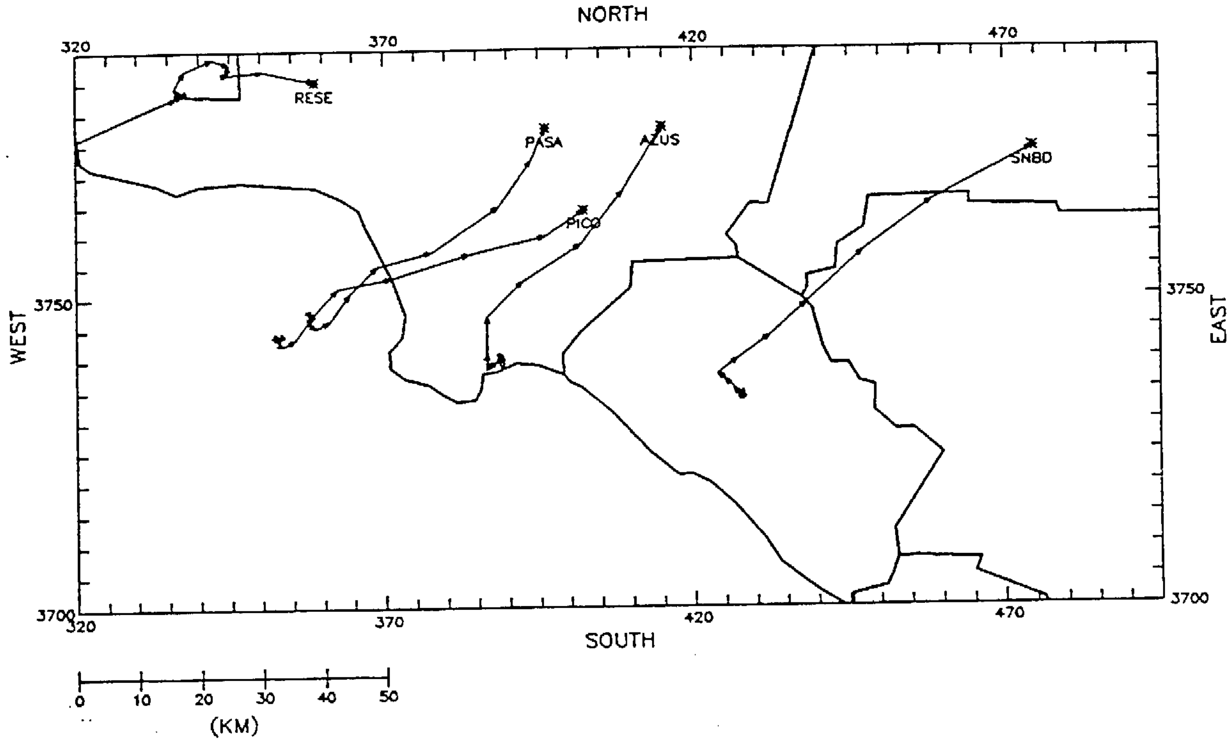


SCAQMD WIND SITES 1 (10M)
1600 PST 8AUG84

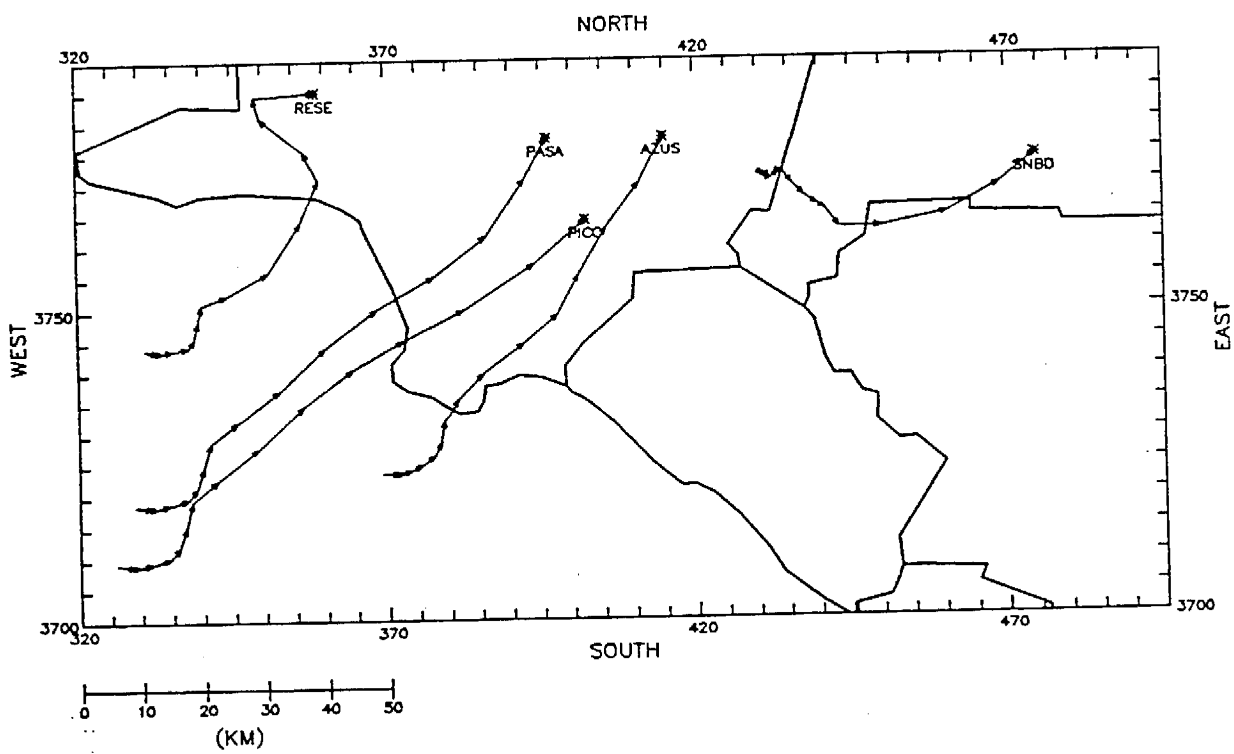


SCAQMD WIND SITES 1 (10M)
1600 PST 23AUG84

FIGURE 5-6. Trajectories for Typical days. Date and time of arrival of air parcel at monitoring sites is indicated in the lower left-hand corner of each plot.

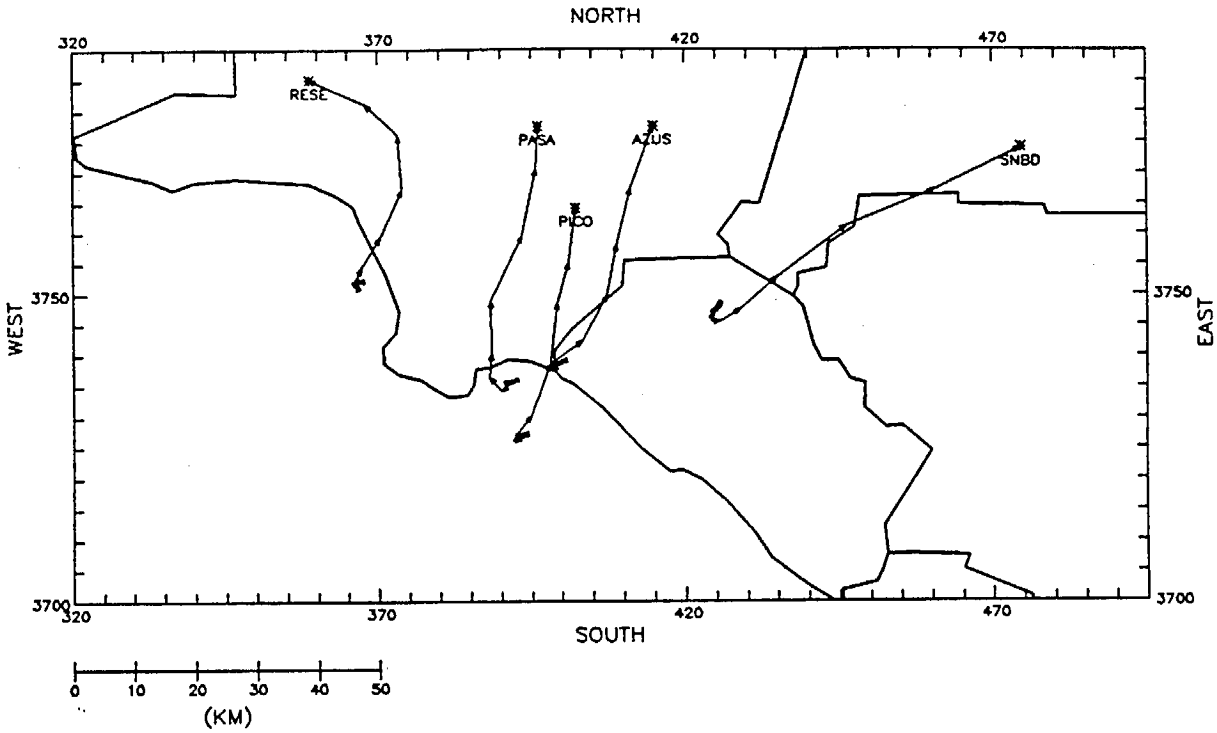


SCAQMD WIND SITES 1 (10M)
1600 PST 29AUG84

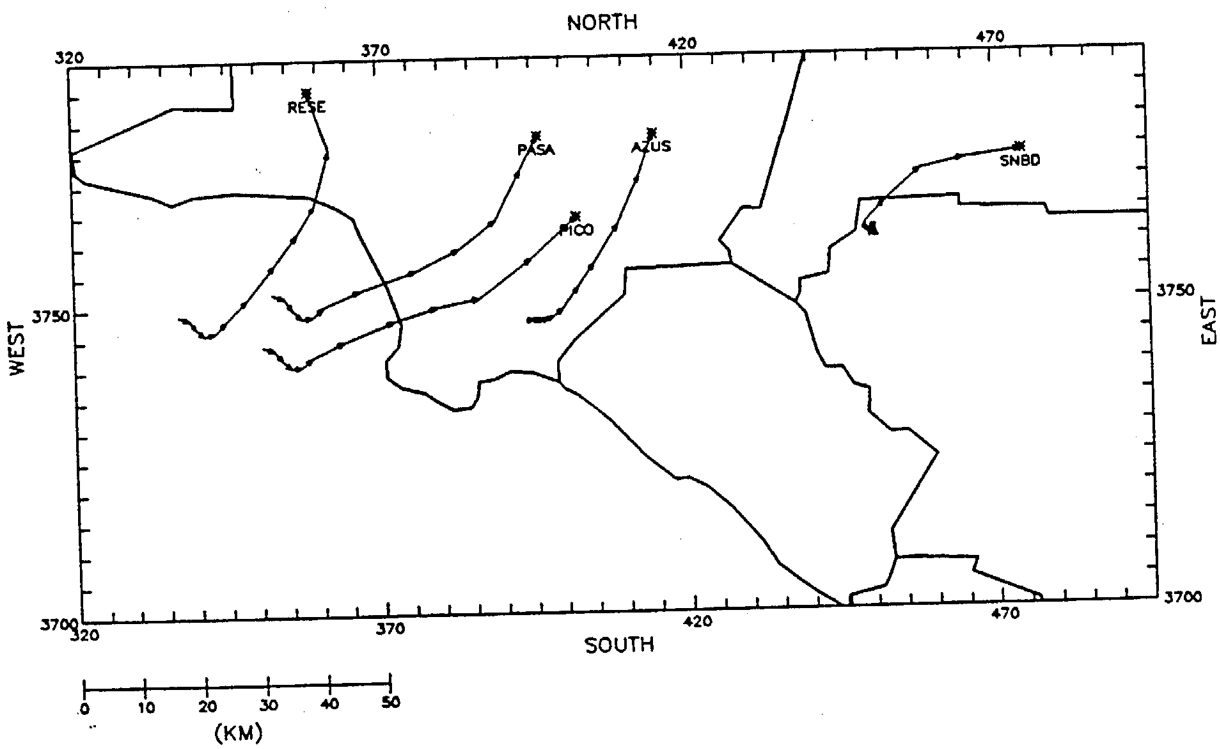


SCAQMD WIND SITES 1 (10M)
1900 PST 18JUL85

FIGURE 5-6. Continued.

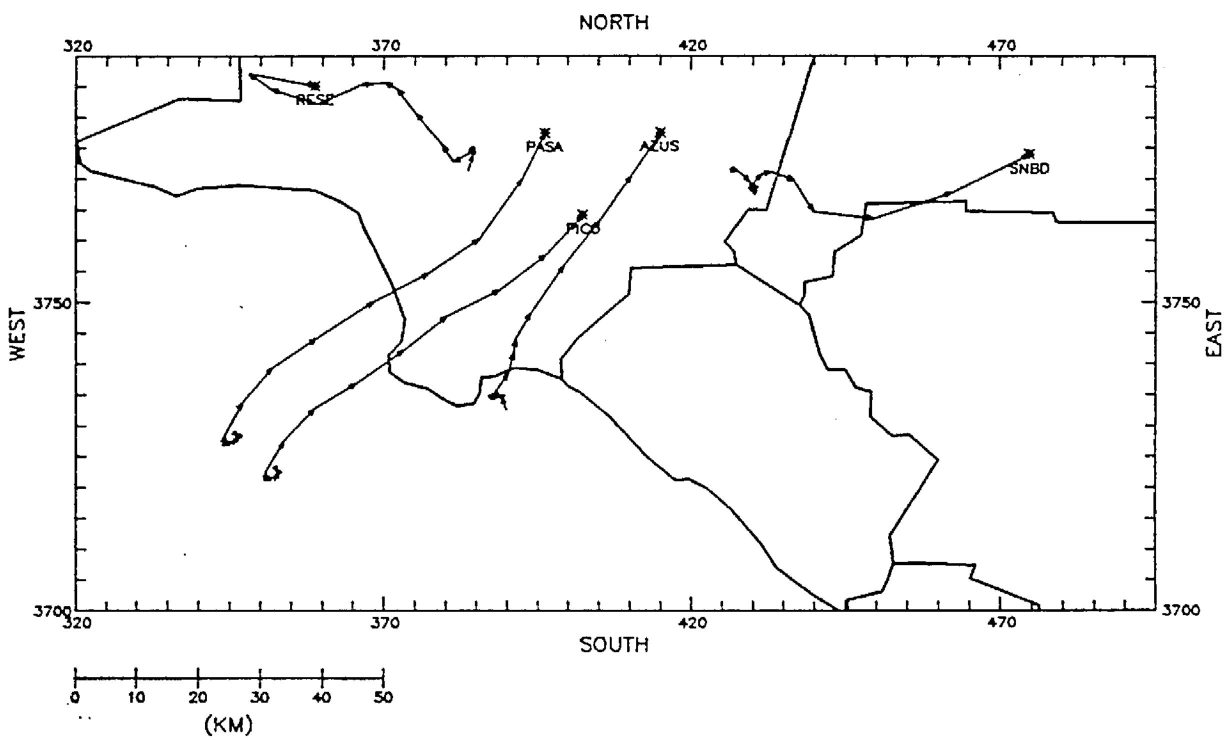


SCAQMD WIND SITES 1 (10M)
1500 PST 7AUG85



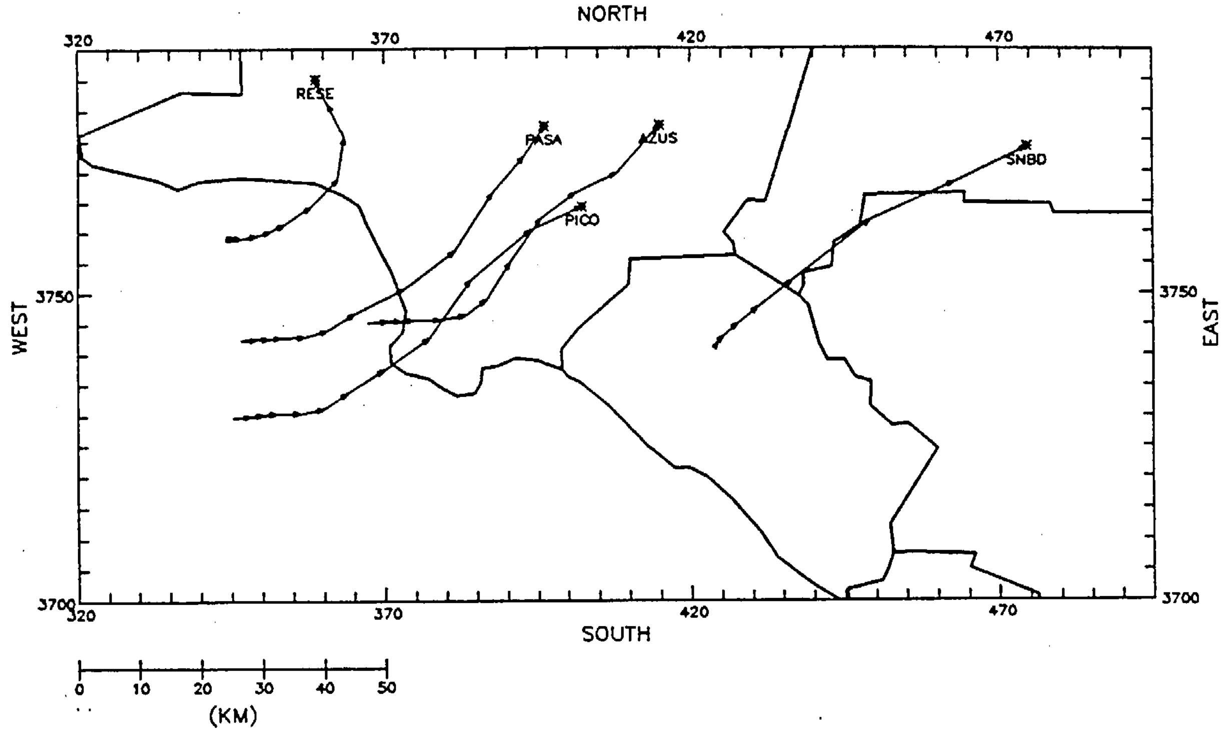
SCAQMD WIND SITES 1 (10M)
1500 PST 22AUG85

FIGURE 5-6. Continued.

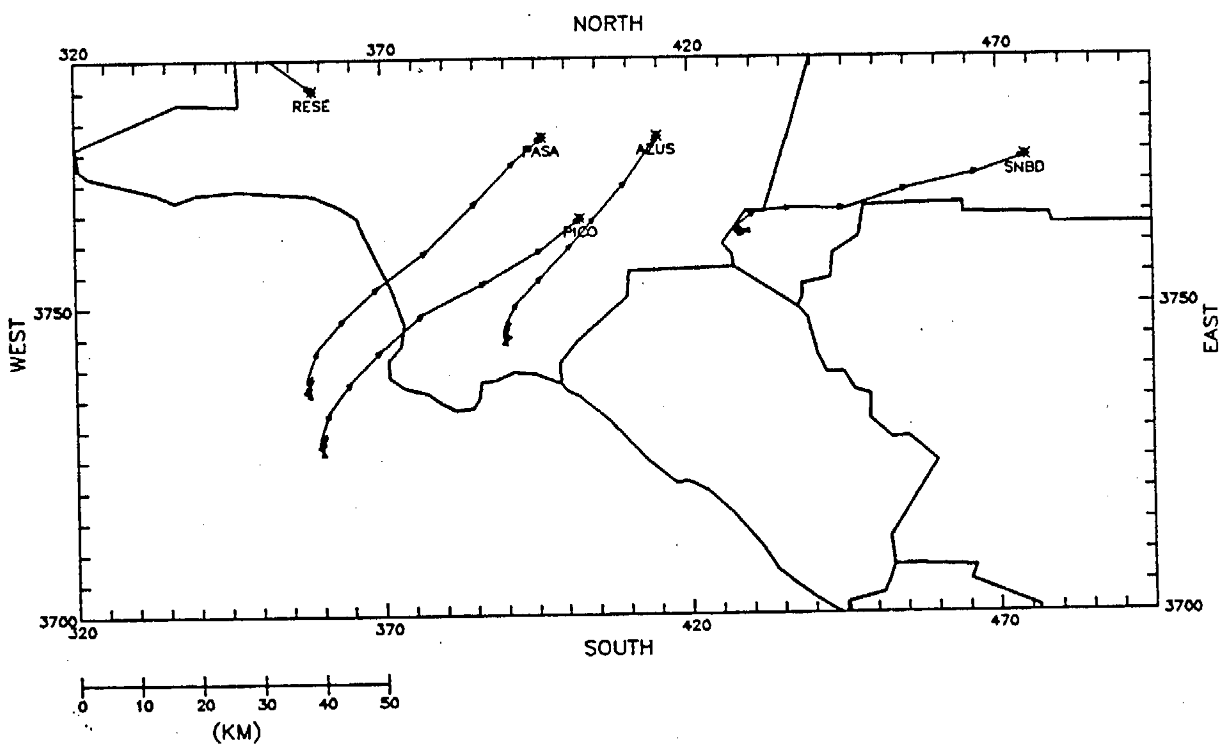


SCAQMD WIND SITES 1 (10M)
1700 PST 22MAY85

FIGURE 5-6. Concluded.



SCAQMD WIND SITES 1 (10M)
1500 PST 16AUG84



SCAQMD WIND SITES 1 (10M)
1700 PST 2OCT85

FIGURE 5-7. Trajectories for Partial Southern Route days. Date and time of arrival of air parcel at monitoring sites is indicated in the lower left-hand corner of each plot.

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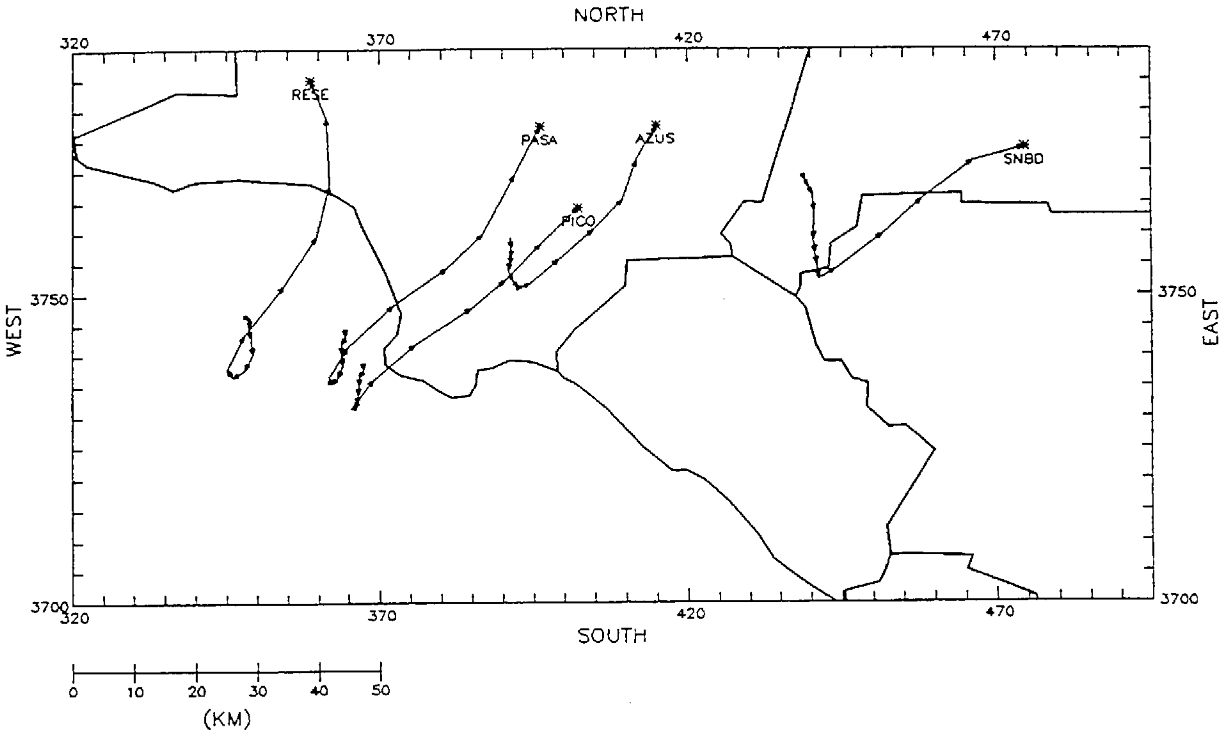
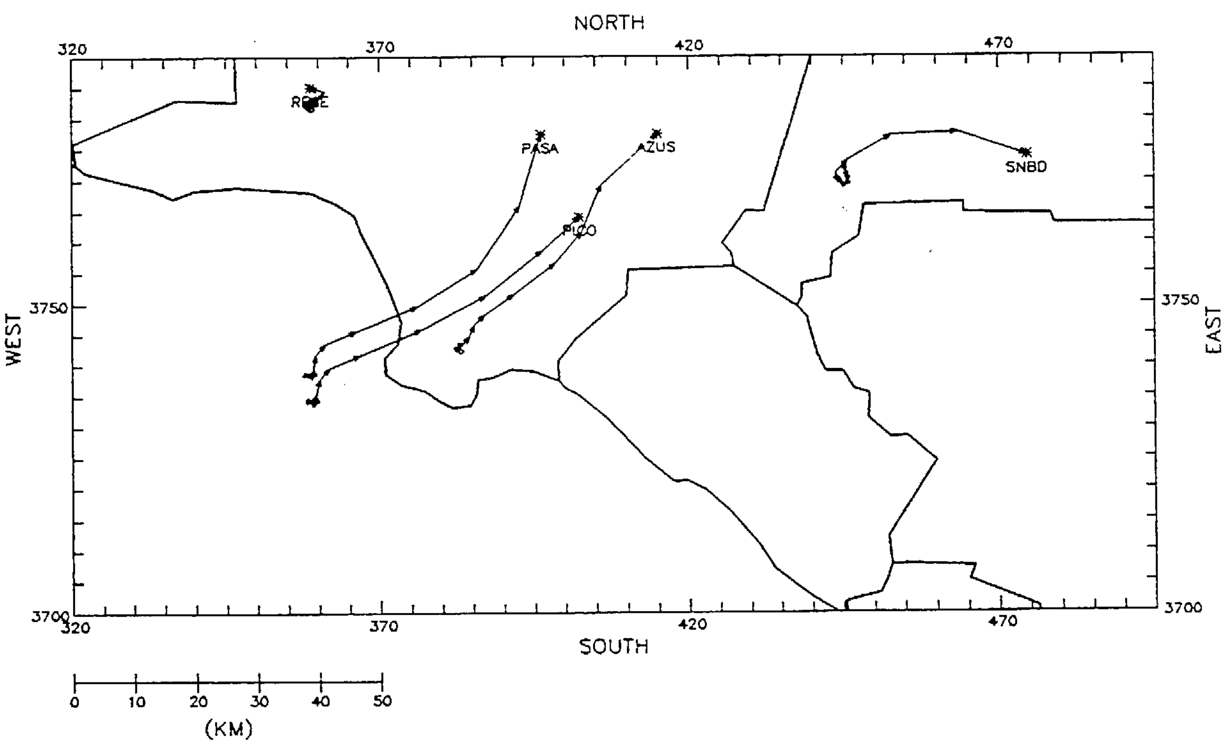
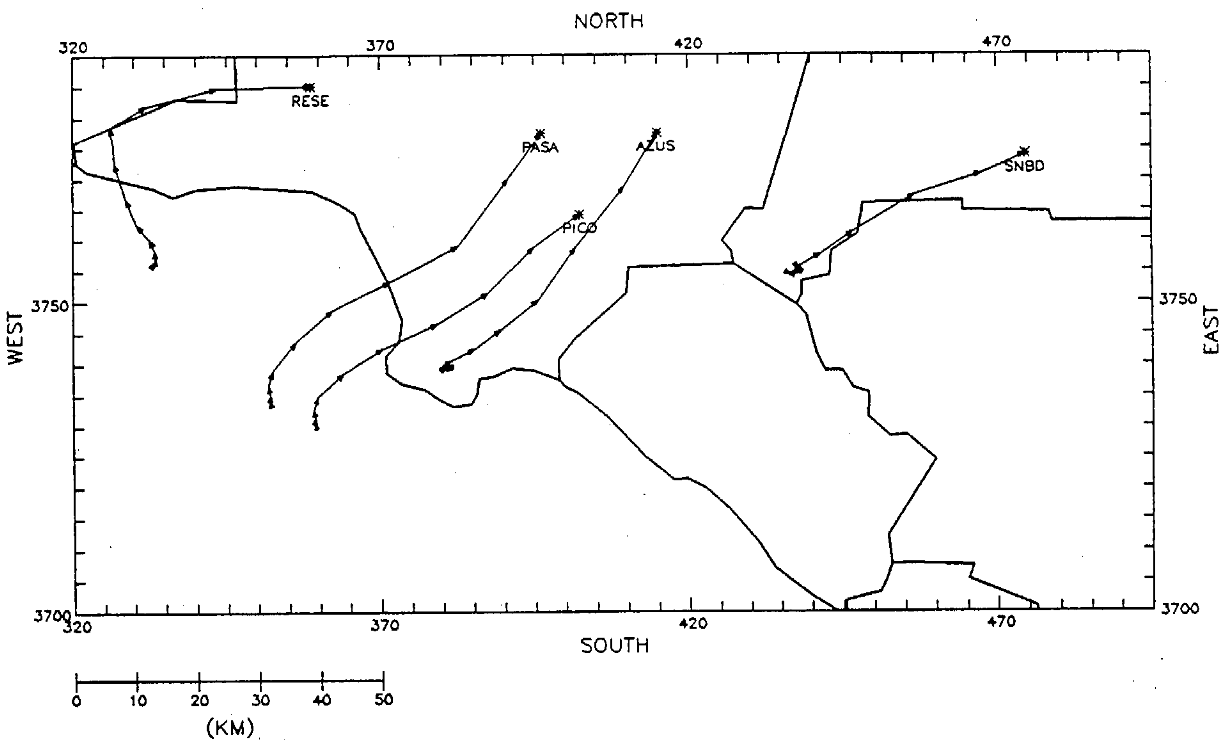


SCAQMD WIND SITES 1 (10M)
1700 PST 12SEP85



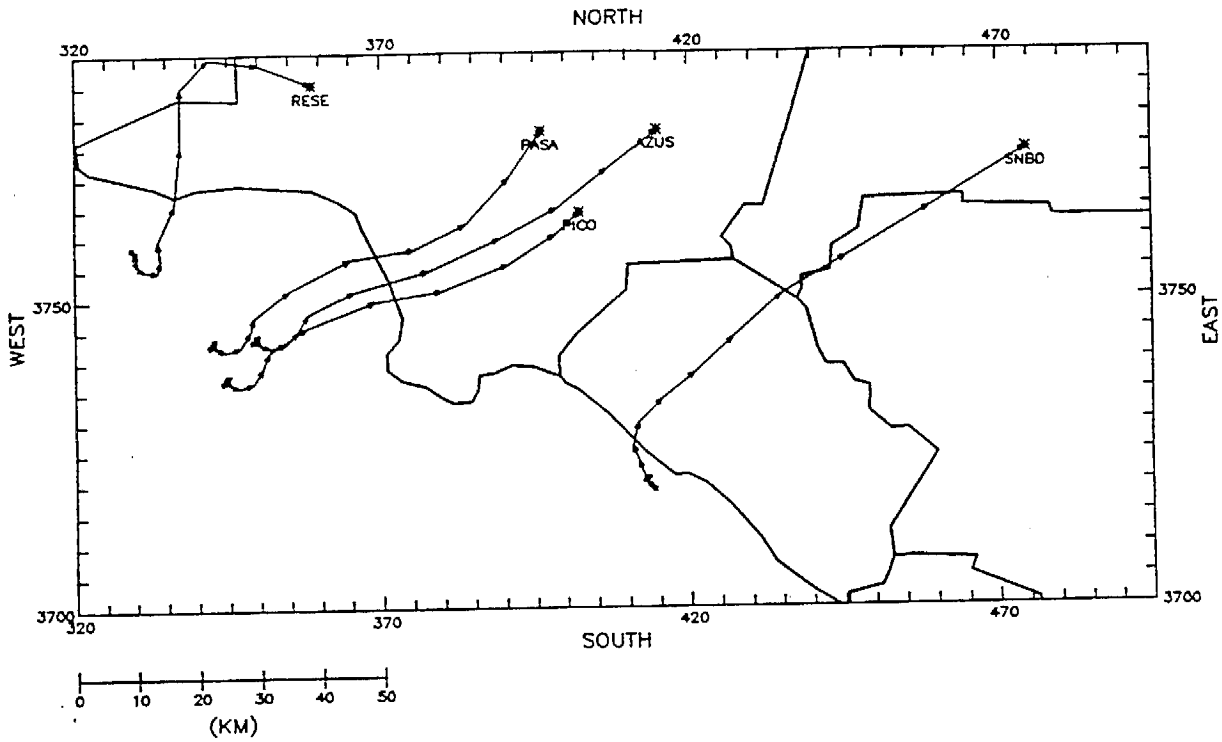
SCAQMD WIND SITES 1 (10M)
1500 PST 18SEP84

FIGURE 5-7. Continued.

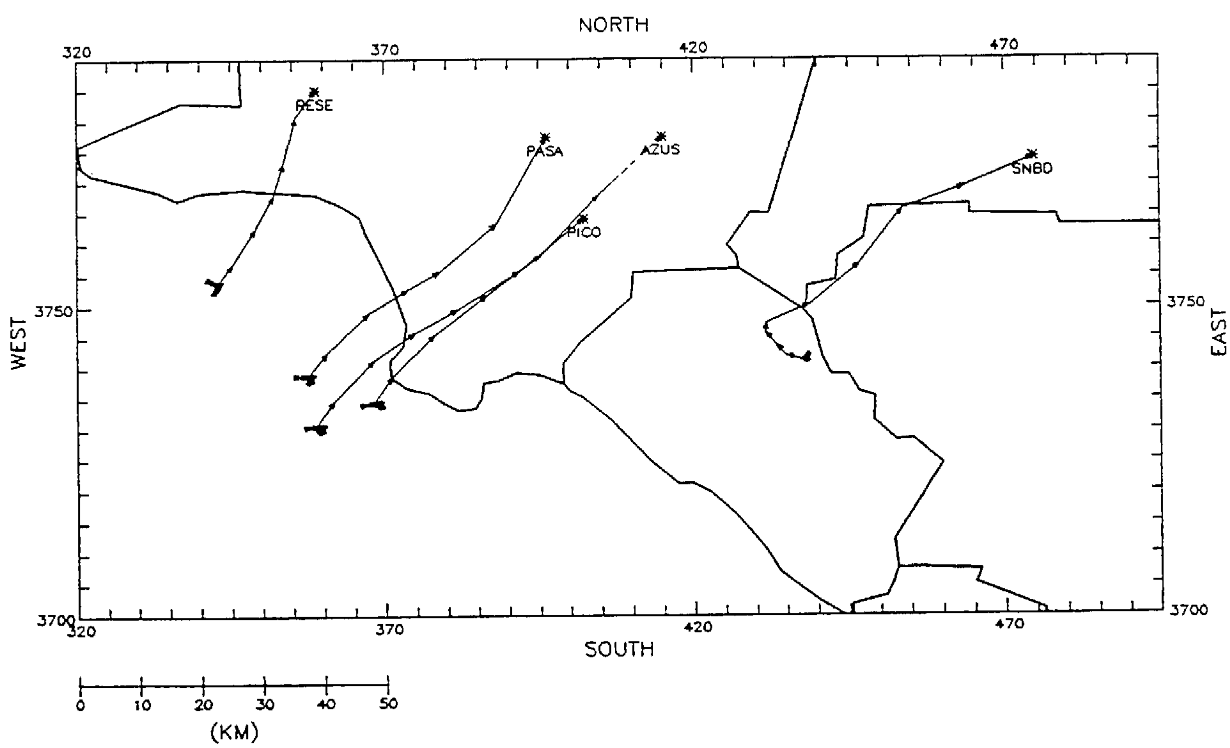


SCAQMD WIND SITES 1 (10M)
1600 PST 28AUG85

FIGURE 5-7. Concluded.

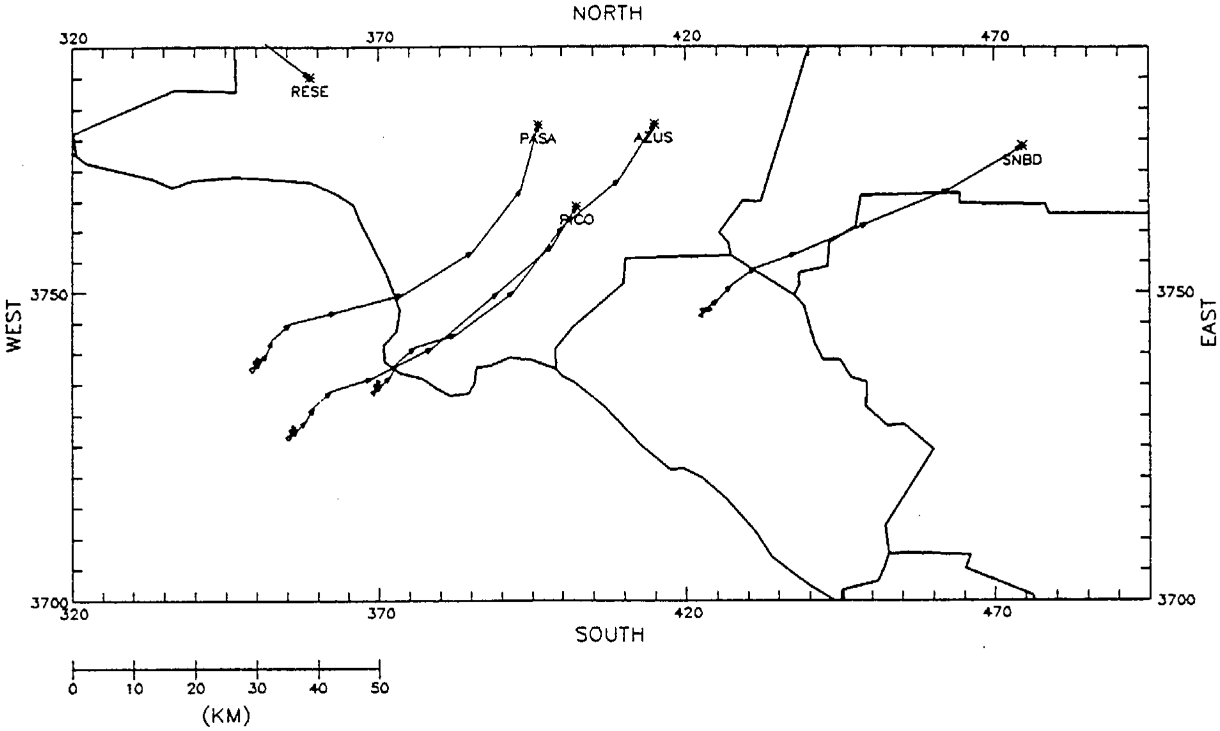


SCAQMD WIND SITES 1 (10M)
1800 PST 5SEP84

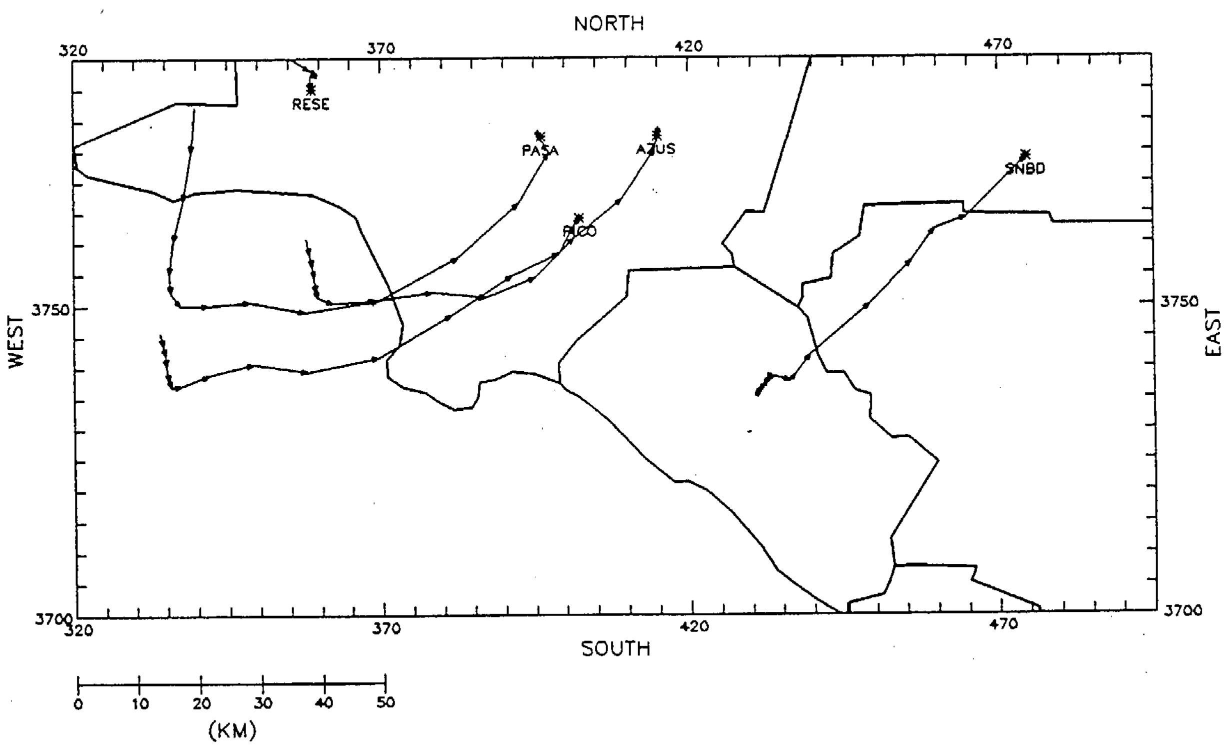


SCAQMD WIND SITES 1 (10M)
1700 PST 8MAY84

FIGURE 5-8. Trajectories for Southern Route days. Date and time of arrival of air parcel at monitoring sites is indicated in the lower left-hand corner of each plot.

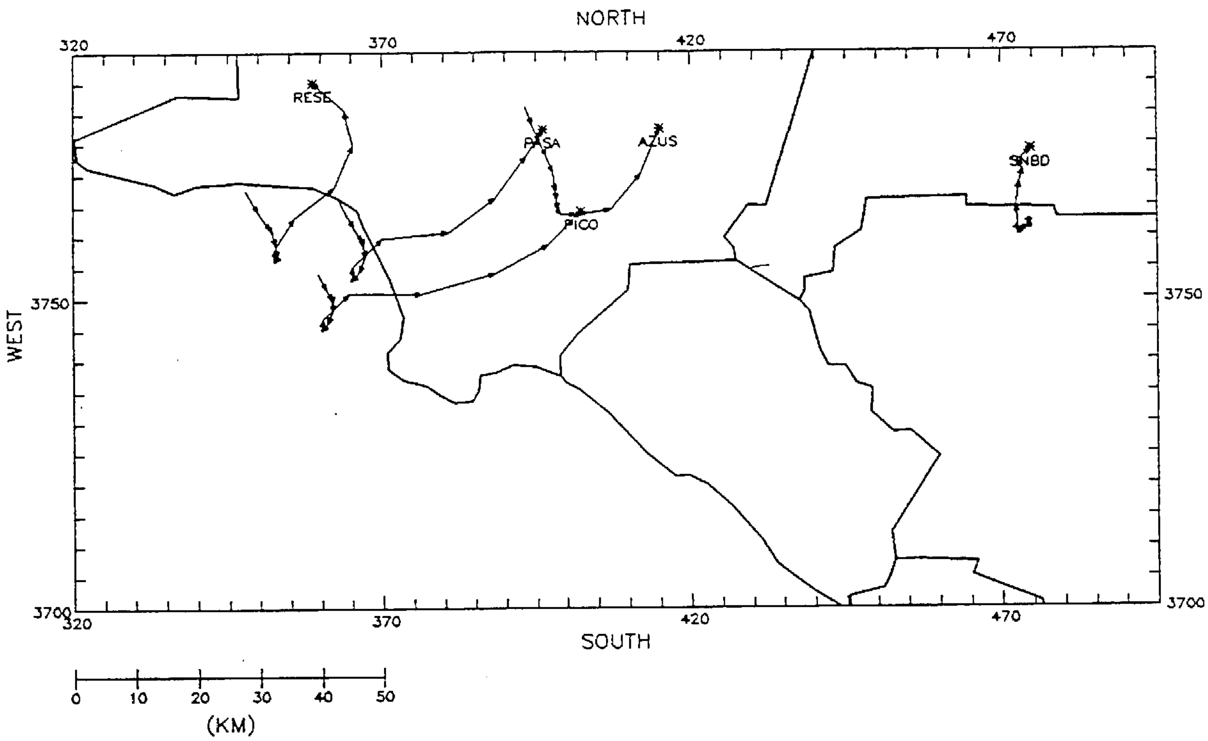


SCAQMD WIND SITES 1 (10M)
1600 PST 19SEP84



SCAQMD WIND SITES 1 (10M)
1900 PST 25SEP84

FIGURE 5-8. Continued.



SCAQMD WIND SITES 1 (10M)
1600 PST 23OCT85

FIGURE 5-8. Concluded.

some days, early morning transport to the northwest similar to that seen on Eddy days can be identified, but this is not always the case. In general, trajectories on Partial Eddy days differ from those on Eddy days in that there is stronger inland transport in the afternoons, thus resulting in trajectories that originate further away from the monitors.

Trajectories on Typical pattern days exhibit a high degree of variability. Trajectories on some days are similar to Eddy patterns, others are similar to Partial Eddy patterns, and the rest are altogether different. Morning wind shifts are evident on many days but no consistent pattern is discernible.

Many of the trajectories on Southern Route and Partial Southern Route days share a common feature: A shift during the late morning from northerly winds to a southwesterly sea breeze which continues on into the afternoon. This pattern leads to increased air parcel residence times over the ocean and over the western, high emissions density portions of the basin during the mornings and slightly reduced afternoon inland penetration. We can thus see how this type of trajectory path will produce the type of ozone concentration distributions observed for Southern Route and Partial Southern Route days in the pilot study.

In summary, trajectories on the various Eddy days analyzed are somewhat similar to one another and follow a characteristic pattern that is created by a morning wind shift from the east or southeast through south to the southwest. Trajectories on many of the Southern Route and Partial Southern Route days are also similar to one another, with a late morning wind shift from north to southwest. No such consistent pattern is evident for any of the other source history categories.

The trajectory analysis results presented above represent an initial attempt to identify the flow patterns associated with each source history category. Although the results suggest that some patterns may be present, clearly more work is needed to verify this and to more clearly identify the pattern characteristics. Suggestions for additional trajectory analyses are presented in Section 7.

Although these diurnal profile and trajectory analyses are limited in scope, the results obtained thus far indicate that the source history classifications are at least partially successful in identifying distinct ozone episode patterns. However, in considering the above results in conjunction with those from the pilot study, it appears that the currently available data do not allow us to unequivocally distinguish between all of Zeldin's categories either on the basis of ozone concentration patterns or meteorological data. Therefore, we focussed our attention on a simplification of the source history category structure as described in the following section.

6 DEVELOPMENT AND APPLICATION OF METEOROLOGICAL CATEGORIES

In this section we review the analysis of meteorological conditions associated with Zeldin's source history categories conducted by Rosenbaum (1990) and use Rosenbaum's meteorological classification criteria to identify likely Eddy and Partial Southern Route or Southern Route days. We then explore the relationship between meteorological conditions and ozone concentrations within each category and use these relationships to calculate meteorologically adjusted ozone concentration trends.

DEVELOPMENT OF METEOROLOGICAL CATEGORIES

As described in Section 4, our attempts to identify clear-cut meteorological signatures for each of Zeldin's source history categories have been largely unsuccessful. Rosenbaum (1990) describes additional work designed to improve upon this result. Rosenbaum first redefined Zeldin's categories in terms of the unique patterns of relative daily maximum ozone concentrations associated with each category (the relative concentrations are defined and discussed in Section 3). Thus, these redefined categories ("ozone patterns") are based only on the spatial distribution of relative maximum ozone concentrations over the basin; meteorological conditions are not included in the definitions. In recognition of the difficulties involved in developing reliable category definitions of this type, Rosenbaum simplified Zeldin's category structure by combining Eddy and Partial Eddy days into a new Eddy ozone pattern, Typical and Typical with Eddy Winds into a new Typical pattern, and Southern Route and Partial Southern Route into a new Southern Route pattern. Numerical definitions of each of these ozone patterns are presented in Rosenbaum's report. This report also presents a comparison of the classification of days during the pilot study period into ozone patterns and into Zeldin's source history categories (see Rosenbaum, 1990, Table 2). These results indicate good agreement between the two categorization schemes, at least for days during the pilot study period.

Rosenbaum examined correlations between the three ozone patterns she defined (Eddy, Typical, and Southern Route; low ozone days were excluded from the analysis) and a set of daily meteorological conditions. By including new surface and upper-air data in the analysis, an attempt was made to improve upon the poor correlations between meteorological conditions and Zeldin's original source history categories described in Section 3. Among the new data examined were additional 3-hourly surface observations of wind speed, direction and temperature at LAX, San Diego and

Las Vegas, and upper-air observations (wind speed, direction and temperature at the surface, 850 and 500 mb) from twice daily soundings at Oakland, Vandenberg, San Diego, Desert Rock (Las Vegas), and Ely. Particular attention was paid to wind directions along the coast, to differences in 850 and 500 mb heights between Vandenberg (assumed to be reasonably representative of the Los Angeles area) and the other upper air sites, and to differences in sea level pressure between LAX, Las Vegas and San Diego. Numerous classification trees and side-by-side boxplots similar to those presented in Figures 3-5 through 3-29 were constructed. From these results, it was determined that surface wind directions and sea level pressure gradients were most closely related to the ozone patterns; neither the winds aloft nor pressure height gradients were more important than the surface conditions in determining the ozone pattern (Rosenbaum, personal communication, 1990).

Because of the difficulties involved in identifying meteorological signatures for each ozone pattern, Rosenbaum chose to focus attention on just the two most clearly unique patterns: Eddy and Southern Route. She developed criteria based on sea level pressure gradients and wind directions designed to minimize the chance of assigning a day to a category that does not have the matching ozone pattern (e.g., minimize the chance of assigning a day with Typical ozone pattern to the Eddy category). These criteria are reproduced in Table 6-1. In general, the criteria reflect the finding that Eddy days are associated with lower pressure to the east and higher pressure to the south of LAX, thus resulting in generally south to southwest winds along the San Diego coast. Southern Route days, on the other hand, are associated with slightly higher pressure to the east and lower pressure to the south of LAX, thus resulting in northwesterly through northeasterly winds along the San Diego coast in the afternoons and northerly to offshore winds at LAX in the mornings.

The meteorological criteria in Table 6-1 were used to classify all days during the study period (Tuesdays, Wednesdays and Thursdays, May-October, 1980-1988). Days not meeting the criteria for either the Eddy or Southern Route pattern are assigned to an "Uncertain" category. Rosenbaum compared the resulting classification of days to the classification by ozone pattern and to Zeldin's source history classification. The comparison, performed both for the 1983-1985 pilot study period and the entire 1980-1988 period, is reproduced in Table 6-2. As intended in the formulation of the meteorological criteria in Table 6-1, a large fraction of days during the pilot study period in the Southern Route and Eddy meteorological categories have the corresponding ozone patterns (83 and 95 percent, respectively). In addition, this relationship holds up reasonably well when applied to data from all years, thus providing us with some confidence that the meteorological criteria are not simply tailored to the peculiarities of the pilot study data set. Since the meteorological classification criteria are designed to be restrictive, the fractions of Southern Route and Eddy ozone pattern days that end up in the corresponding meteorological category are not particularly high (44 and 58 percent, respectively, over all years), as shown at the bottom of Table 6-2. The remaining Southern Route and Eddy days are put into the Uncertain category together with the Typical and Offshore ozone pattern days. One additional feature to note in Table 6-2 is that most of the days in

TABLE 6-1. Meteorological criteria developed by Rosenbaum (1990) designed to identify days with Eddy and Southern Route type ozone patterns (SLP = sea level pressure, PST = Pacific Standard Time, WD = wind direction).

Parameter	Criteria
Day is Eddy if:	
LAX - Las Vegas SLP, 1600 PST	> 7.75 mb
or	
(LAX - Las Vegas SLP, 1600 PST	> 1.75 mb
and	
LAX - San Diego SLP, 1600 PST	< -0.45)
or	
(LAX - Las Vegas SLP, 1600 PST	1.85 - 3.55 mb
and	
LAX - San Diego SLP, 1600 PST	< 0.05 mb
and	
San Diego WD, 0700 PST	112.5° - 247.5°)
or	
(LAX - Las Vegas SLP, 1600 PST	> 3.55 mb
and	
San Diego WD, 0700 PST	157.5° - 247.5°)
or	
(LAX - Las Vegas SLP, 1600 PST	< 3.55 mb
and	
LAX - San Diego SLP, 1600 PST	< 0.05 mb
and	
LAX - Las Vegas SLP, 0700 PST	< -0.35 mb
and	
LAX WD 1000 PST	< 67.5° or > 112.5°
and	
San Diego WD, 0700 PST	112.5° - 292.5°)
Day is Southern Route if:	
(LAX - Las Vegas SLP, 1600 PST	< 1.75 mb
and	
LAX - Las Vegas SLP 0700 PST	< -0.75 mb
and	
LAX - San Diego SLP, 1600 PST	> 0.05 mb)
or	
(LAX - Las Vegas SLP, 1600 PST	< 0.70 mb
and	
LAX - Las Vegas SLP, 0700 PST	< -0.75 mb
and	
LAX WD, 0700 PST	< 157.5° or > 247.5°
and	
San Diego WD, 1600 PST	> 337.5° or < 67.5°)

TABLE 6-2. Comparison of meteorological categories, ozone patterns, and Zeldin's classification scheme for Tuesdays, Wednesdays, and Thursdays 1983-1985 and 1980-1988 (from Rosenbaum, 1990).

	Meteorological Classification	
	Southern Route	Eddy
Fraction of meteorological category days with matching ozone pattern		
1983-1985	0.83	0.95
1980-1988	0.75	0.88
Fraction of days with matching Zeldin classification*		
1983-1985	0.82	0.83
1980-1988	N/A	N/A
Fraction of ozone pattern days that match corresponding meteorological category		
1983-1985	0.46	0.68
1980-1988	0.44	0.58

* Matches defined as: Meteorological Southern Route category = Zeldin's Partial Southern Route and Southern Route, Meteorological Eddy category = Zeldin's Eddy and Partial Eddy.

each meteorological category are associated with the proper corresponding categories in Zeldin's classification (82 and 83 percent, respectively). From the results in Table 6-2, then, we conclude that the meteorological criteria listed in Table 6-1 are adequate for the purpose of identifying days with Southern Route and Eddy ozone patterns, but that many days with these ozone patterns do not exhibit the expected meteorological features and thus are placed in the Uncertain meteorological category.

Given the extensive analysis of meteorological data conducted by Rosenbaum, and the fact that the analysis produced a relatively successful formulation of meteorological criteria that can be used to identify Eddy and Southern Route ozone pattern days, we decided to use this meteorological classification for the remaining portions of our study.

RELATIONSHIP OF WITHIN-CATEGORY OZONE TO METEOROLOGY

A principal objective of our analysis is the examination of the relationships between ozone formation and meteorological conditions. Given the existence of different source history categories, it is reasonable to assume that such relationships may differ from one category to the next, as well as from one subregion to the next as suggested by the limited analysis conducted in the pilot study (see Section 3). In this section, we describe the results of two different approaches used to identify the meteorological factors most closely associated with ozone formation at four key subregions (North Coast, San Fernando Valley, San Gabriel Valley and Inland Valley) within the Eddy, Southern Route and Uncertain meteorological categories. In each case, a series of statistical models are used to describe the day-to-day fluctuations in subregion average ozone concentrations (for 1980-1988) with respect to changes in meteorological conditions. Those combinations of meteorological variables that result in the best models for each subregion and category are noted.

Variable Selection

A large number of meteorological variables and combinations of variables may be considered in the development of a statistical model to describe day-to-day ozone variations. Since we are interested only in variations within each meteorological category, we focus our attention primarily on variables not already thought to be accounted for in the categorization procedure. Thus, variables related primarily to flow patterns (such as wind directions, pressure gradients, etc.) were not considered. Variables were selected under the assumption that ozone formation depends primarily on temperature, dispersion and insolation. Variables found to be correlated with within-category concentration variations in the pilot study were also included here. These considerations led to the selection of the following variables:

T850	850 mb temperature; known to be closely correlated with ozone in the SOCAB, indicates inversion conditions and is closely related to daily maximum temperatures at inland sites.
LAGT850	Previous day's T850; indicates potential for carry-over of ozone and precursors from one day to the next.
DTSBDLAX	Difference in daily maximum temperature between LAX and San Bernardino (= TMAXSBD - TMAXLAX); provides an indication of the strength of the thermal sea breeze forcing.
VENT	Ventilation (wind speed times mixing height) at the coast (= BASEHT * AWSLAX); greater ventilation indicates stronger sea breeze and lower coastal ozone concentrations.
DELTAT	Temperature difference between top and base of inversion; indicates inversion strength.
RADAM	Sum of 0700 and 1000 PST cloud cover observations at LAX. Indicates morning coastal insolation potential and condition of marine layer.
RADPM	Sum of 1300 and 1600 PST cloud cover observations at LAX. Indicates afternoon coastal insolation potential and condition of marine layer.
AWSxxx	Daily average wind speed at a station near the subregion of interest (xxx = station*); indicates local dispersion conditions.
AVRHxxx	Daily average relative humidity at a station near the subregion of interest (xxx = station*); indicates local air mass (i.e., marine or continental) and water vapor effects on photochemical reactions.
TMAXxxx	Daily maximum temperature at a station near the subregion of interest (xxx = station*); indicates local maximum temperature.

* As indicated, local effects on ozone formation in each subregion are accounted for by using wind speed, relative humidity and temperature data from a station within or near the subregion. For the North Coast subregion, observations from LAX were used, for the San Fernando and San Gabriel valleys, Burbank (BUR) observations were used, and for the Inland Valley, San Bernardino (SBD) observations were used.

These meteorological variables were used in two different regression procedures as described next.

CART Analysis

Regression trees were grown using the CART methodology with the subregion average daily maximum ozone concentration as the dependent variable and the meteorological variables as the regressors. A separate tree was created for each subregion/category combination. Cross-validation estimates of the relative errors were used to determine the optimal tree size as described in Appendix A of the project work plan (Stoeckenius et al., 1989). Results are summarized in Table 6-3 in terms of the cross-validation estimates of the fraction of variance in ozone concentrations that is explained by partitioning days into the terminal nodes of the trees. In comparing these values with R-square values determined from linear regressions reported elsewhere in this report and by other investigators, it is important to remember that the linear regression R-square values are based on the data set used to estimate the regression parameters and thus are likely to be significantly larger than cross-validation R-square values.

As indicated in Table 6-3, for all categories at the North Coast subregion, CART determined that no data split was capable of significantly reducing the variance as determined by the cross-validation estimates. This finding is consistent with the poor regression for the coastal subregions noted in the pilot study and may be at least partially the result of the comparatively small within-category ozone variance along the coast. A similar situation holds for the Southern Route category at the Inland Valley subregion. In this case, the relatively small number of Southern Route days may be a contributing factor. Best results were obtained for the inland subregions for the meteorological categories with reasonably large numbers of data points (Eddy and Uncertain).

An important feature of the CART methodology is the ranking of regressors on the basis of their overall importance to the tree structure. In general, variables that are used to define splits at a number of different nodes or that produce splits nearly as good as the actual splitting variable used at a number of different nodes are assigned a high ranking. Ranks are relative; the most important variable is assigned a value of 100 (see Breiman et al., 1984 for additional information). Although there is no single "correct" or best way to develop importance ranks, the CART procedure gives a reasonable indication of which variables are most significant with respect to the proportion of variance explained by the regression tree.

Table 6-4 lists the relative importance of rankings as determined by CART for each run made. As each column represents a single run, the rankings are relative within the column and the numerical values cannot be directly compared across columns. Table 6-4 reveals several interesting differences in variable importance between meteorological categories at the same subregion. For example, in the San Fernando

TABLE 6-3. Cross-validation results of CART regression tree analyses for subregion average daily maximum ozone 1980-1988.

	Fraction of Variance Explained*		
	Eddy	Southern Route	Uncertain
North Coast	~0	~0	~0
San Fernando Valley	0.28	0.33	0.25
San Gabriel Valley	0.46	0.29	0.45
Inland Valley	0.47	~0	0.39

* Equals cross-validation estimates of one minus ratio of pooled sum of squares in terminal nodes to total sum of squares. Values shown as being approximately equal to zero (~0) indicate cases in which the cross-validation estimates showed no advantage in constructing a tree.

TABLE 6-4. Relative importance of meteorological variables as determined by CART analyses (see text).

Variable*	San Fernando			San Gabriel			Inland Valley		
	Eddy	Southern	Uncertain	Eddy	Southern	Uncertain	Eddy	Southern	Uncertain
T850	99	100	100	100	100	100	100	84	100
LAGT850	57	80	49	54	51	51	52	64	56
DTSBDLAX	100	9	35	100	17	82	69	100	79
VENT	51	19	10	43	5	10	44	37	17
DELTAT	55	40	54	41	23	49	65	12	50
RADAM	11	9	0	13	0	17	6	0	4
RADPM	4	11	1	12	0	11	1	0	4
Local average wind speed†	9	9	12	6	17	11	6	11	7
Local average relative humidity†	7	19	5	28	12	13	11	3	26
Local maximum temperature†	77	23	33	75	4	60	75	18	82

* Variables are defined in Table __.

† Stations selected to represent local conditions are Burbank (San Fernando Valley and San Gabriel Valley subregions) and San Bernardino (Inland Valley subregion).

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and San Gabriel valleys, the coastal to inland temperature gradient, DTSBDLAX, is nearly as important as T850 in explaining ozone variations on Eddy days but not on Southern Route days. A possible explanation for this is that Eddy days are generally characterized by a deep marine layer which extends well inland, thus keeping ozone levels relatively low (see, for example, Figure 3-33 e). Therefore, it is likely that those Eddy days with higher-than-average ozone are characterized by warmer inland temperatures while the coast remains cool, thus setting up a relationship between DTSBDLAX and inland ozone concentrations. Similarly, the local daily maximum temperature also has a higher relative importance on Eddy days than on Southern Route days. A slightly different situation occurs at the Inland Valley subregion, where DTSBDLAX is actually the most important variable on Southern Route days and of less importance on Eddy days. This may be a result of the fact that higher-than-average ozone values on Southern Route days require the presence of sufficient thermal sea breeze forcing to transport pollutants and precursors into the Inland Valley area from the western portions of the basin. On the "typical" Southern Route day, this forcing is damped and ozone concentrations are lower.

Best Subsets Linear Regression Analysis

Another approach to identifying variations in the relationship between ozone concentrations and meteorological conditions from one meteorological category to the next is through a series of linear regression analyses in which regression models are constructed for all possible subsets of the available meteorological variables and the variable group that produces the best fit to the data is identified. We performed such a best subsets regression analysis using the same meteorological variables used in the CART analysis previously described. In this case, however, the three "local" variables assigned to each subregion were included in the pool of variables available to the regression procedure for all of the subregions. Thus, for example, the San Bernardino maximum temperature (TMAXSBD) was considered as a possible regressor for all of the subregions, not just for the Inland Valley subregion.

Since the total number of possible subsets of all sizes of the 16 meteorological variables considered is extremely large, we limited the maximum subset size to four variables. This restriction is reasonable since the stepwise regression analysis conducted in the pilot study suggests that the inclusion of more than a few variables in the regression equation does not lead to a significant increase in adjusted R-square values.

Regressions using all possible subsets of between 1 and 4 variables were conducted for each meteorological category. Subsets were then sorted in order of decreasing adjusted R-square value. Typically, the R-square values for the top 10 or so subsets were within a few percent of one another, and it would therefore be misleading to report only that subset that resulted in the highest value. Instead, we counted the number of times each regressor was included in the top 10 subsets. Results are shown in Table 6-5, together with the highest and tenth highest adjusted R-square

TABLE 6-5. Number of times regressors appear in top 10 best subset regressions.

	T850	LAGT850	DTSBDLAX	VENT	DELTAT	RADAM	RADPM	AWSLAX	AWSBVR	AWSSBD	AVRHLAX	AVRHBUR	AVRHSBD	TMAXLAX	TMAXBUR	TMAXSBD	Highest Adj. R-sq	10th Highest Adj. R-sq
North Coast																		
Eddy	5		1	4	1			10		1			7		8		.25	.22
Southern Route	10	3			4	10						5					.33	.30
Uncertain			10	8							3	1	8	1		1	.24	.21
San Fernando Valley																		
Eddy	10		9											9			.48	.46
Southern Route	10		8												10		.42	.40
Uncertain		4	10	4						5			10				.20	.19
San Gabriel Valley																		
Eddy	10		10								10						.53	.51
Southern Route	10		10												10		.61	.58
Uncertain			10									10	10				.40	.39
Inland Valley																		
Eddy	10		10											8			.57	.55
Southern Route	10		10												10		.41	.37
Uncertain		7	10									4	10				.31	.29

9002 8r1 8

value. Curiously, the results differ significantly from those obtained from the CART analysis. In particular, T850 and DTSBDLAX appear to be about equally important on both Eddy and Southern Route days at the inland subregions, and the relative humidity variables, which were not identified as being important in the CART analysis, were included in each of the top 10 subsets in the Uncertain category at the inland subregions. Of course, although a variable such as AVRHBUR may be included in each subset, it is not necessarily as important in increasing the R-square as a variable such as DTSBDLAX, which is also included in each subset (see, e.g., San Gabriel Valley-Uncertain). Thus, additional criteria for subset selection may be needed to more clearly identify the most important regressors.

OZONE TREND CALCULATIONS

As noted previously, one of the principal applications of a meteorological classification procedure is the calculation of ozone trends that are adjusted to account for the influence of year-to-year changes in meteorological conditions. In this section we first calculate and describe separate ozone trends for each meteorological category. We then describe the calculation of adjusted trends using two alternative adjustment procedures.

Calculation of Trends for Each Meteorological Category

Three-year running averages of the seasonal mean subregion average daily maximum ozone concentration were calculated for each meteorological category at each subregion. Trends for four key subregions (North Coast, San Fernando Valley, San Gabriel Valley and Inland Valley) are shown in Figure 6-1. In general, trends differ from one meteorological category to the next, suggesting that changes in precursor emission patterns over the years have had different effects on ozone for different meteorological regimes. Clearly defined differences between categories in the magnitude of seasonal mean ozone concentrations are also evident. This is especially evident in the North Coast, where Southern Route days are consistently associated with higher ozone levels than are Eddy days. Despite fixing meteorological conditions by category, however, it is evident from Figure 6-1 that a fair amount of year-to-year variability in ozone levels remains. Much of this variability can likely be attributed to remaining within-category variations in weather conditions. In the following sections, we describe the result of applying two alternative techniques designed to remove the remaining variability.

Calculation of Adjusted Trends

One potential application of the meteorological classification scheme just described is in the adjustment of ozone concentration trends to account for the influence of variations in meteorological conditions. Year-to-year fluctuations in seasonal mean

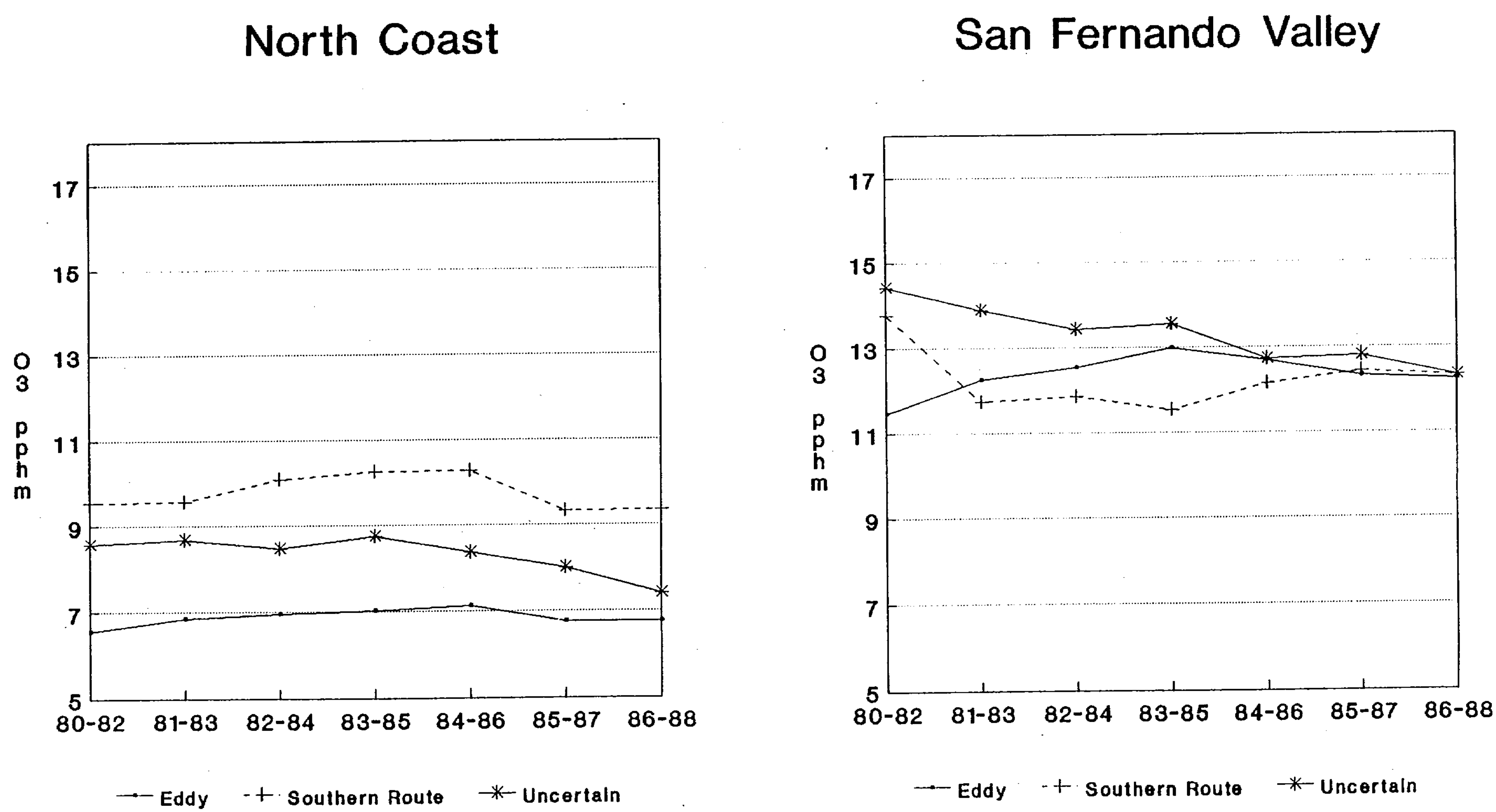

FIGURE 6-1. Seasonal mean ozone concentrations for each meteorological category: 3-year running averages.

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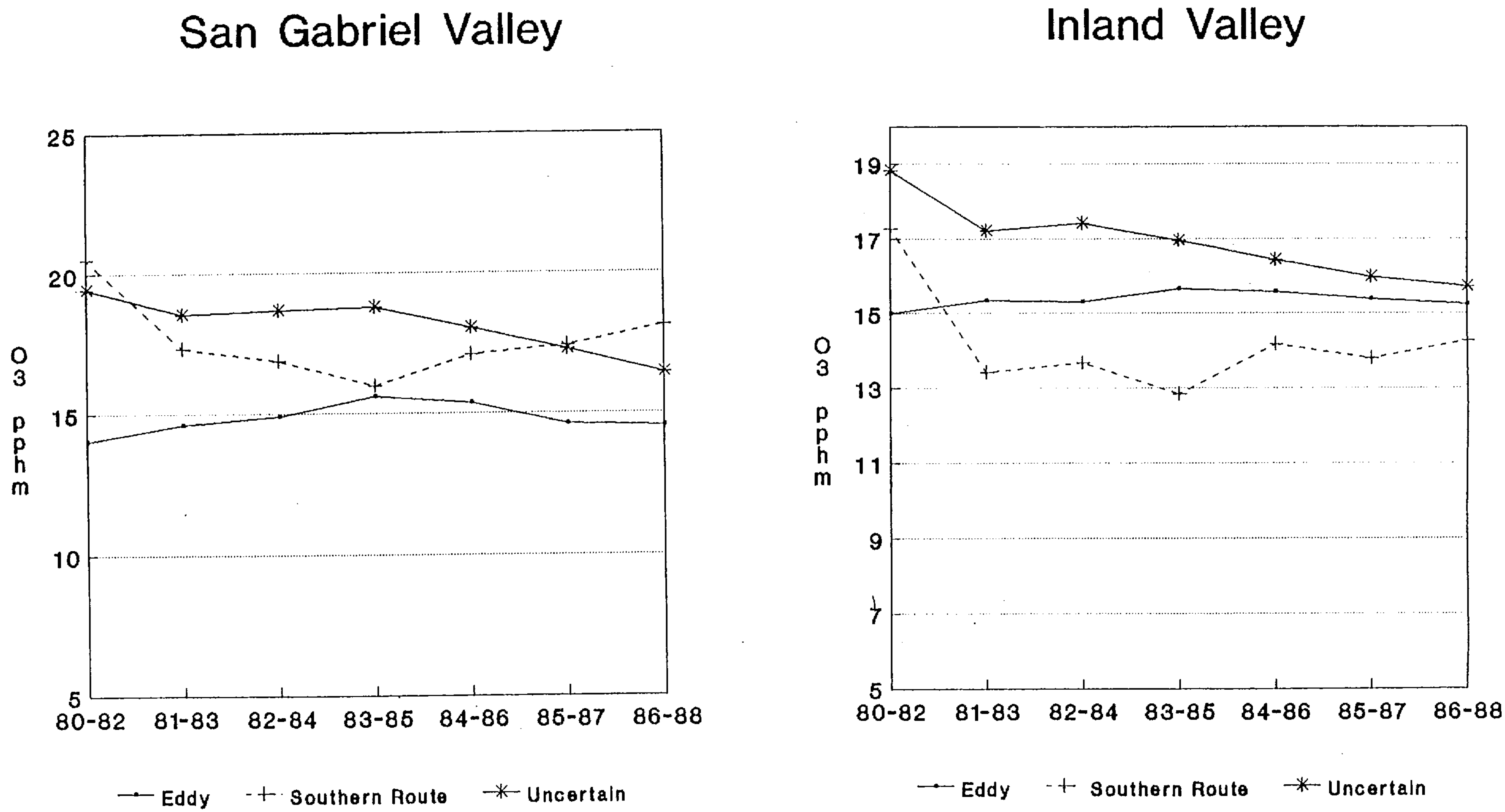

FIGURE 6-1. Concluded.

90028

ozone concentrations resulting from fluctuations in the frequency and severity of meteorological conditions conducive to ozone formation often make it difficult to identify long-term underlying concentration trends. By developing quantitative relationships between daily maximum ozone concentrations and daily meteorological conditions, it is possible to adjust the observed ozone concentrations to account for the variable influence of meteorology, thus exposing the underlying trend. In this section, we describe and apply two different techniques for developing such adjusted trends: One based on the meteorological categorization scheme described here, and another developed by Davidson et al. (1985).

Adjustments Based on Meteorological Categories

Classification of meteorological conditions into source history categories in the manner described can serve as the first step in building a statistical model that provides the required quantitative ozone-meteorology relationship. However, as shown in Table 6-6, the source history categorization procedure only accounts for a small portion of the ozone concentration variance. Therefore, additional refinement of the statistical model is necessary to account for the remaining within-category fluctuations. These fluctuations are believed to result primarily from day-to-day variations in temperature and inversion conditions that can occur within a given source history category.

We accounted for within-category ozone variations by performing a series of linear regression analyses with the subregion average daily maximum ozone concentration serving as the dependent variable. Regressors were selected from among the large number of meteorological variables in our data set (see Section 2) by restricting attention to those that (1) are available for the entire 1980-1988 study period (allowing for occasional missing values), and (2) were identified as being most closely related to within-category concentration fluctuations as indicated by the step-wise regression analyses performed in the pilot study (see Section 3). Examination of the pilot study regression results indicates that the latter criterion is satisfied primarily by temperature variables and variables describing the condition of the overhead temperature inversion. Therefore, the following variables were selected for the trends adjustment regressions:

T850	LAX/UCLA/LMU 13z sounding 850 mb temperature (deg. C)
LAGT850	Previous day's T850
TMAXLAX	Daily maximum temperature at LAX (deg. F)
TMAXSBD	Daily maximum temperature at San Bernardino (deg. F)
PGLAXWJF	Surface pressure gradient, LAX-Lancaster, 15z (mb)

TABLE 6-6. Percent of variance in subregion average daily maximum ozone concentrations that is accounted for by the partitioning of days into the Eddy, Southern Route, and Uncertain meteorological categories (based on 1980-1988 data).

Subregion	Percent of Variance Explained
North Coast	9
South Coast	22
Metropolitan	14
San Fernando Valley	2
San Gabriel Valley	7
Inland Metropolitan	18
Inland Foothill	5
Inland Valley	3
Mountain	11

DELTAT Inversion top temperature - base temperature from LAX/UCLA/LMU 13z sounding (deg. C)

BASEHT Inversion base height from LAX/UCLA/LMU 13z sounding (ft)

A separate least-squares linear regression analysis was performed using the above variables for each source history category at each subregion. Because of the small number of days falling in some categories during individual years, the regression analysis was performed on overlapping three-year intervals (1980-1982, 1981-1983, ..., 1986-1988). Regression results for three of the seven overlapping three-year periods at four key subregions are summarized in Table 6-7. Similar results were obtained for other time periods and subregions. Because of the small number of data points or the limited range of ozone concentrations for some subregion/year/pattern combinations, some of the regression fits are quite poor, as indicated by the adjusted R-Square values and F-test results in Table 6-7. Despite these problems, the regression equations were used "as is" in the trend adjustment calculations without regard to how well they fit the data. In this way it was possible to obtain a complete set of meteorologically adjusted seasonal mean ozone concentrations that could be compared to values that have been adjusted by an alternative method (see below). It should be recognized, however, that the adjustments for those categories and time periods for which poor regression fits were obtained may be unrealistic.

In the first step of the adjustment process, within-category seasonal mean ozone concentrations adjusted for meteorology were calculated for each category by substituting the long-term (1980-1988) average values of the meteorological variables into the seasonal regression equations. The second step of the adjustment process is designed to account for changes in weather conditions that produce changes in the frequency of occurrence of each meteorological category from one three-year period to the next. These types of meteorological variations can produce variations in ozone concentrations that must be accounted for in the calculation of adjusted seasonal mean concentrations, where the mean is taken over all days in the season, regardless of category. This is accomplished by calculating a weighted average of the within-category adjusted seasonal mean concentrations where the weights are set equal to the long-term (1980-1988) average number of times each category occurs over a three-year interval. The resulting seasonal mean concentrations are thus adjusted both for variations in weather conditions within each meteorological category and for variations in the frequency of occurrence of each category. These values can be interpreted as the concentration that would have been observed had meteorological conditions during each three-year period corresponded to climatological norms.

Adjusted seasonal mean ozone trends calculated in the manner just described are shown for four key subregions in Figure 6-2. These results were obtained by eliminating low ozone days (meteorological category #4) from the analysis. Thus, the weighted averages computed in the second step of the adjustment process were only taken over the first three categories. Figure 6-2 reveals two main features:

DELTAT	Inversion top temperature - base temperature from LAX/UCLA/LMU 13z sounding (deg. C)
BASEHT	Inversion base height from LAX/UCLA/LMU 13z sounding (ft)

A separate least-squares linear regression analysis was performed using the above variables for each source history category at each subregion. Because of the small number of days falling in some categories during individual years, the regression analysis was performed on overlapping three-year intervals (1980-1982, 1981-1983, ..., 1986-1988). Regression results for three of the seven overlapping three-year periods at four key subregions are summarized in Table 6-7. Similar results were obtained for other time periods and subregions. Because of the small number of data points or the limited range of ozone concentrations for some subregion/year/pattern combinations, some of the regression fits are quite poor, as indicated by the adjusted R-Square values and F-test results in Table 6-7. Despite these problems, the regression equations were used "as is" in the trend adjustment calculations without regard to how well they fit the data. In this way it was possible to obtain a complete set of meteorologically adjusted seasonal mean ozone concentrations that could be compared to values that have been adjusted by an alternative method (see below). It should be recognized, however, that the adjustments for those categories and time periods for which poor regression fits were obtained may be unrealistic.

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TABLE 6-7. Results of linear regression analyses for ozone trend adjustment procedure (see text).

Subregion	Category	Adjusted R^2 (Prob > F)[1] 1980-1982	1983-1985	1986-1988
1	Eddy	0.37 (<0.01)	0.19 (<0.01)	0.19 (0.13)
	Southern Route	0.15 (0.43)	0.12 (0.32)	0.24 (0.26)[2]
	Uncertain	0.47 (<0.01)	0.25 (<0.01)	0.04 (0.33)
4	Eddy	0.54 (<0.01)	0.53 (<0.01)	0.64 (<0.01)
	Southern Route	0.81 (0.03)	0.53 (0.02)	-- (0.80)[2,3]
	Uncertain	0.52 (<0.01)	0.35 (<0.01)	0.20 (0.06)
5	Eddy	0.70 (<0.01)	0.66 (<0.01)	0.69 (<0.01)
	Southern Route	0.96 (<0.01)	0.64 (0.01)	0.07 (0.42)[2]
	Uncertain	0.74 (<0.01)	0.63 (<0.01)	0.68 (<0.01)
8	Eddy	0.59 (<0.01)	0.63 (<0.01)	0.73 (<0.01)
	Southern Route	0.91 (0.01)	0.47 (0.04)	0.13 (0.36)[2]
	Uncertain	0.61 (<0.01)	0.62 (<0.01)	0.54 (<0.01)

Notes:

[1] R^2 values have been adjusted to account for degrees of freedom as per (ref). Prob > F indicates probability that regression fit is not significant as determined by the standard analysis of variance F-test.

[2] The regressor TMAXLAX (daily maximum temperature at LAX) was not available for this time period and category and was therefore not used in the regression models for these cases.

[3] Poor regression fit prevented calculation of a meaningful adjusted R-square value in this case.

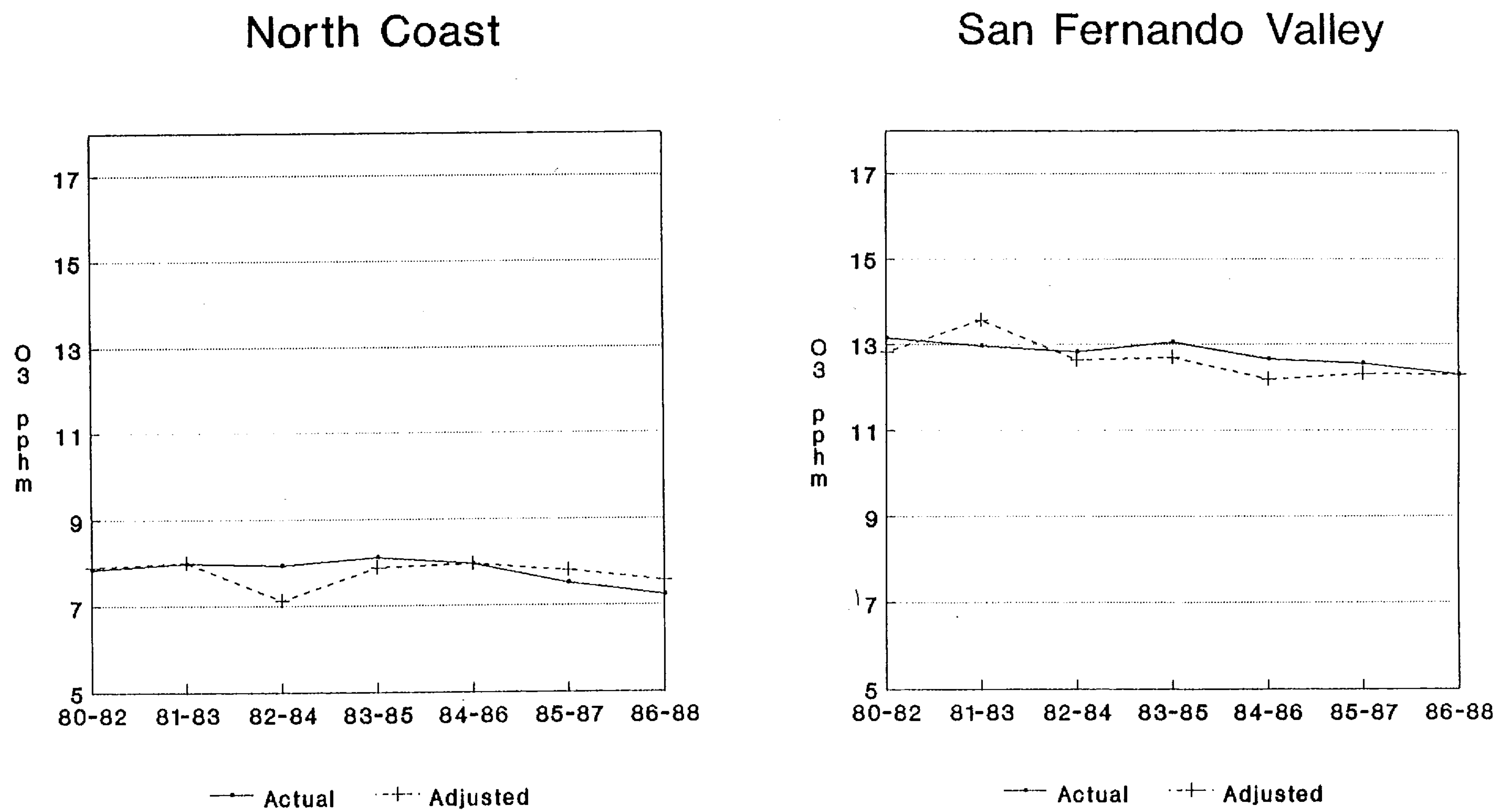

FIGURE 6-2. 3-year running average ozone trends with meteorological category based adjustment procedure applied (low ozone days excluded).

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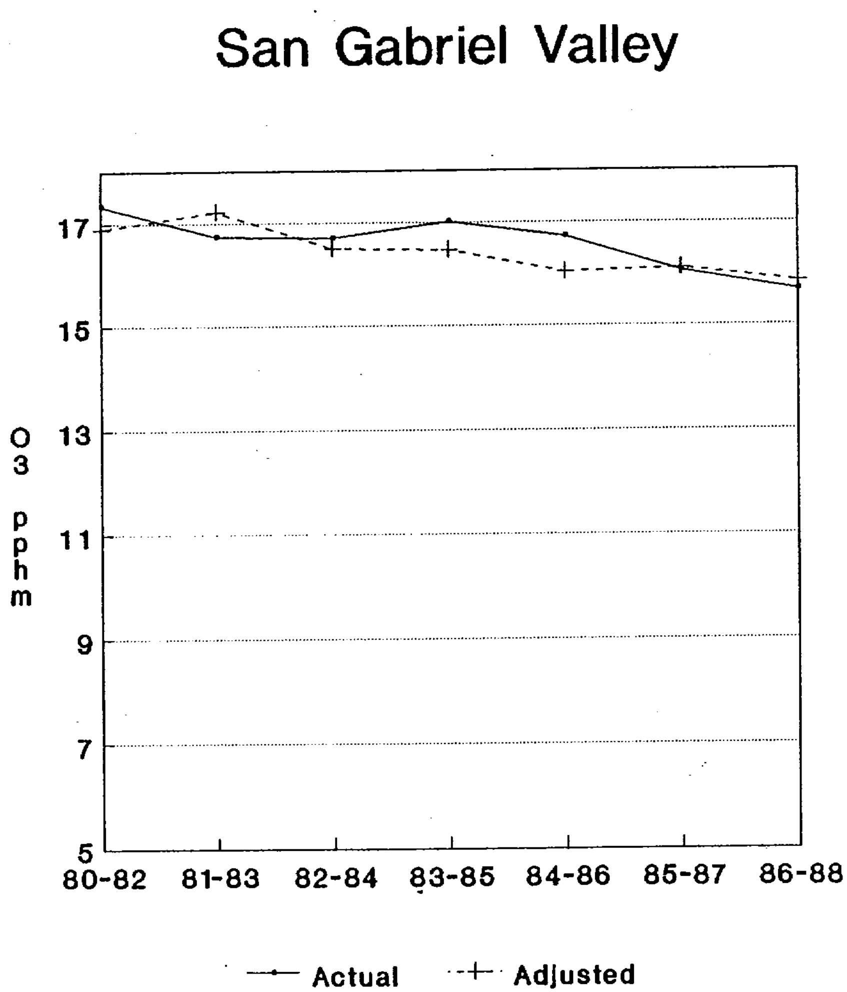

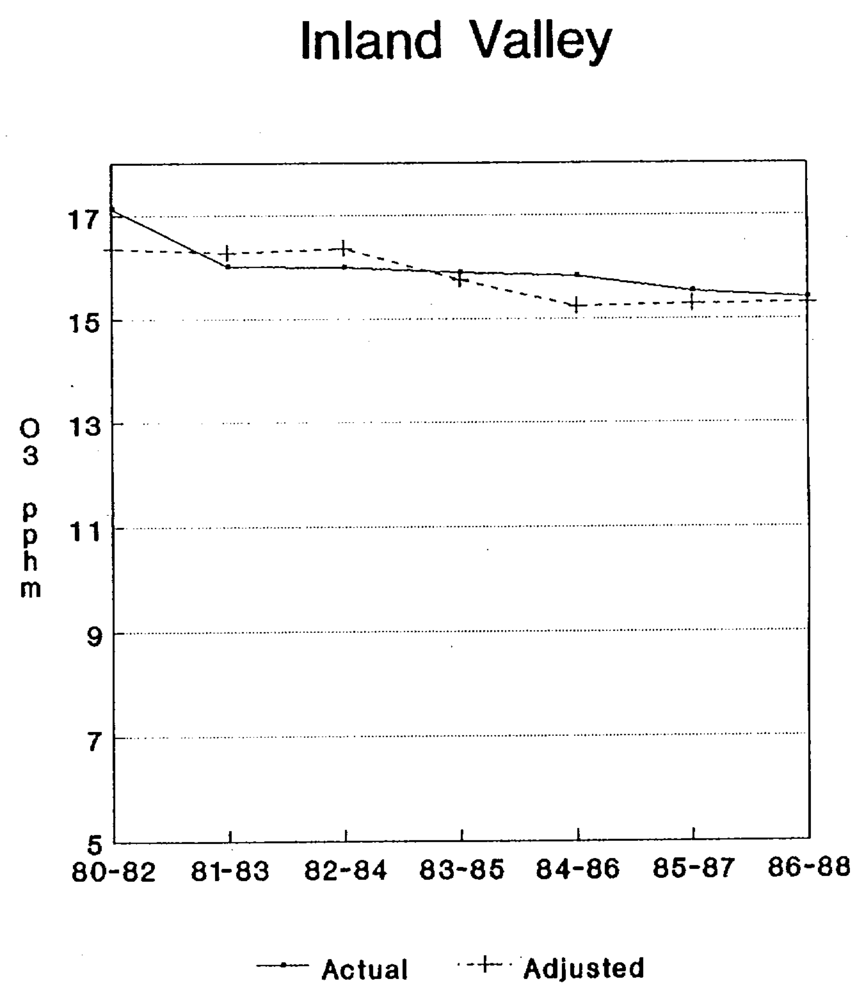

FIGURE 6-2. Concluded.

166

90028

(1) the three category average unadjusted trends are fairly smooth, and no large increases or decreases in concentration are evident although visual inspection suggests slight downward trends at the inland subregions, and (2) the adjusted trends are no smoother (and in some cases less smooth) than the unadjusted trends. The increased variability in the adjusted trends is no doubt the result of the poor regression results noted in Table 6-7. This is especially evident for the 1982-1984 time period at the North Coast, where the adjusted trend takes an explicable dip. From these results it is apparent that more precise relationships between ozone concentrations and weather conditions will need to be developed if the adjustment procedure is to succeed.

The adjustment procedure described above was also applied using all four meteorological categories (i.e., including low ozone days). Similar results were obtained, as shown in Figure 6-3. These results were primarily obtained to provide a set of adjusted trends based on all days (not just days above 8 pphm) that could be compared directly with those obtained using the alternative adjustment procedure described next.

Adjustments Based on 850 mb Temperature Fluctuations

By way of comparison with the adjusted trends just described, we applied an alternative trend adjustment procedure suggested by Davidson et al. (1985). This method makes use of the observation that much of the variability in daily maximum ozone concentrations in the SOCAB can be related to variations in the morning 850 mb temperature. Davidson showed how this relationship can be used to calculate seasonal mean ozone concentrations that have been adjusted to account for year-to-year changes in the mean 850 mb temperature. The adjustment procedure is as follows:

1. Compute a least-squares simple linear regression equation for each ozone season, using the daily maximum ozone concentration as the dependent variable and the daily 850 mb temperature as the regressor.

2. Compute adjusted seasonal mean ozone concentrations by substituting the climatological mean 850 mb temperature into each of the seasonal regression equations, thus obtaining estimates of what the ozone concentration would have been for each season had the 850 mb temperature for that season been equal to the long-term average temperature.

We applied Davidson's method at each subregion using the subregion average daily maximum ozone concentration as the dependent variable and the LAX/UCLA/LMU 13z 850 mb temperature as the regressor for each seasonal regression analysis. The 1980-1988 average 850 mb temperature (= 17.4 deg. C) was then substituted into each equation to obtain adjusted values of the seasonal mean subregion average daily maximum ozone concentration. Results of the calculation are illustrated in Figure 6-4 for four key subregions. Although the adjusted trends appear to smooth out some

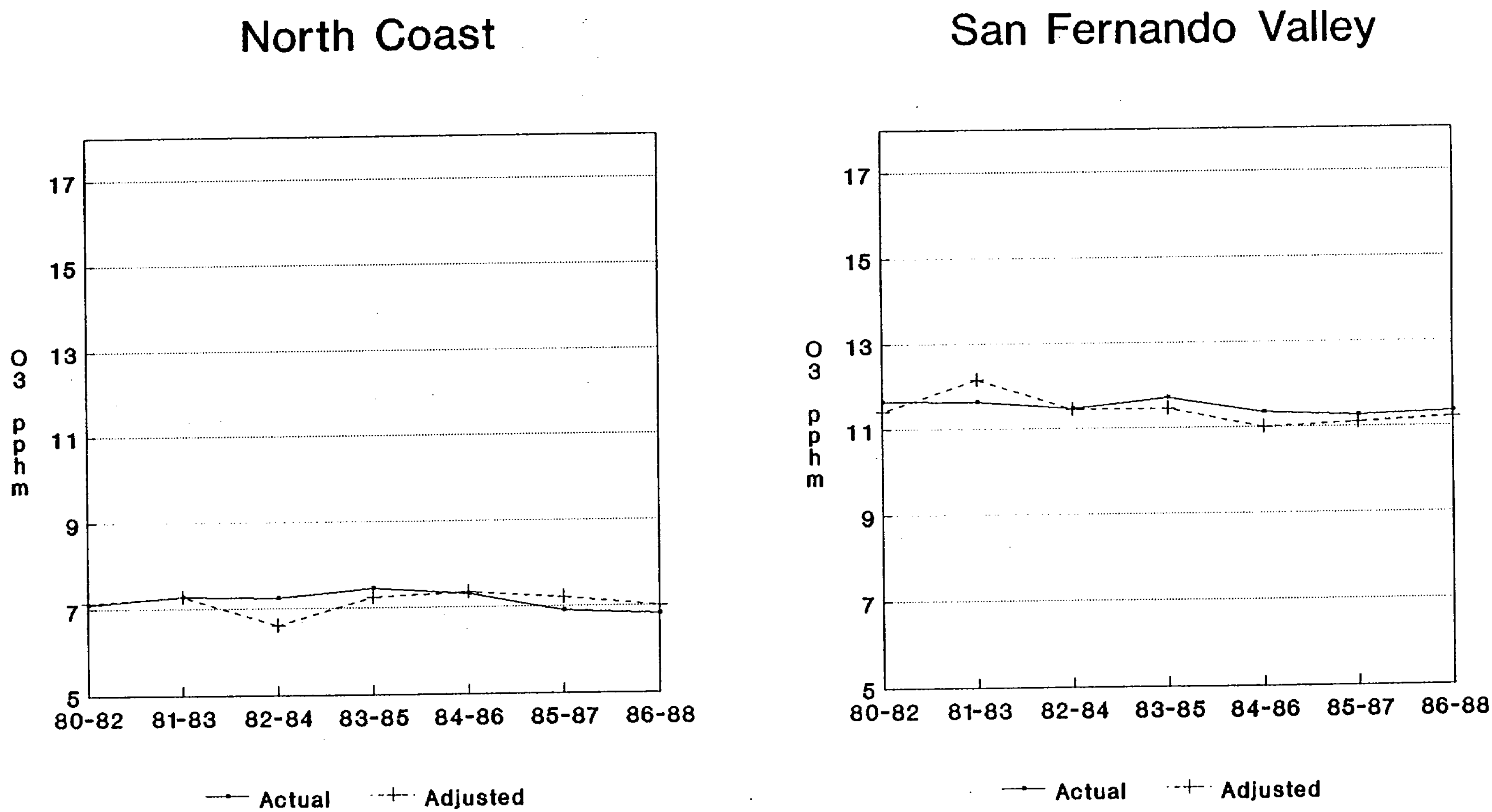

FIGURE 6-3. 3-year running average ozone trends with meteorological category-based adjustment procedure applied (low ozone days included).

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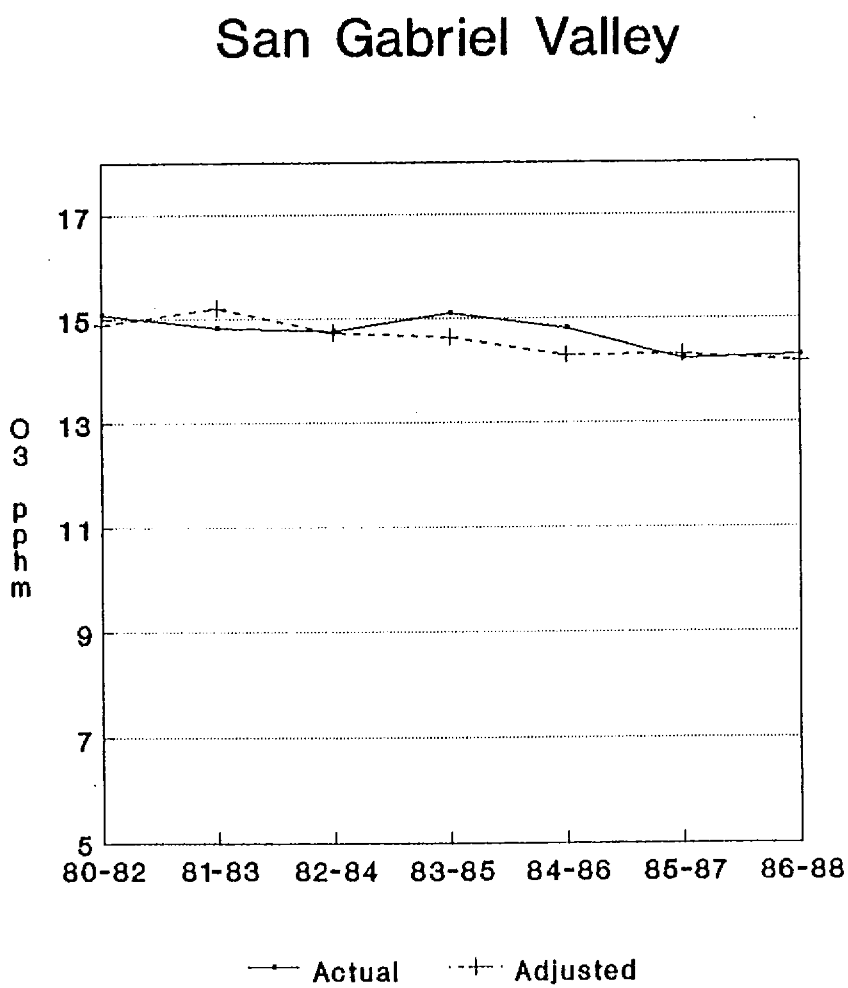

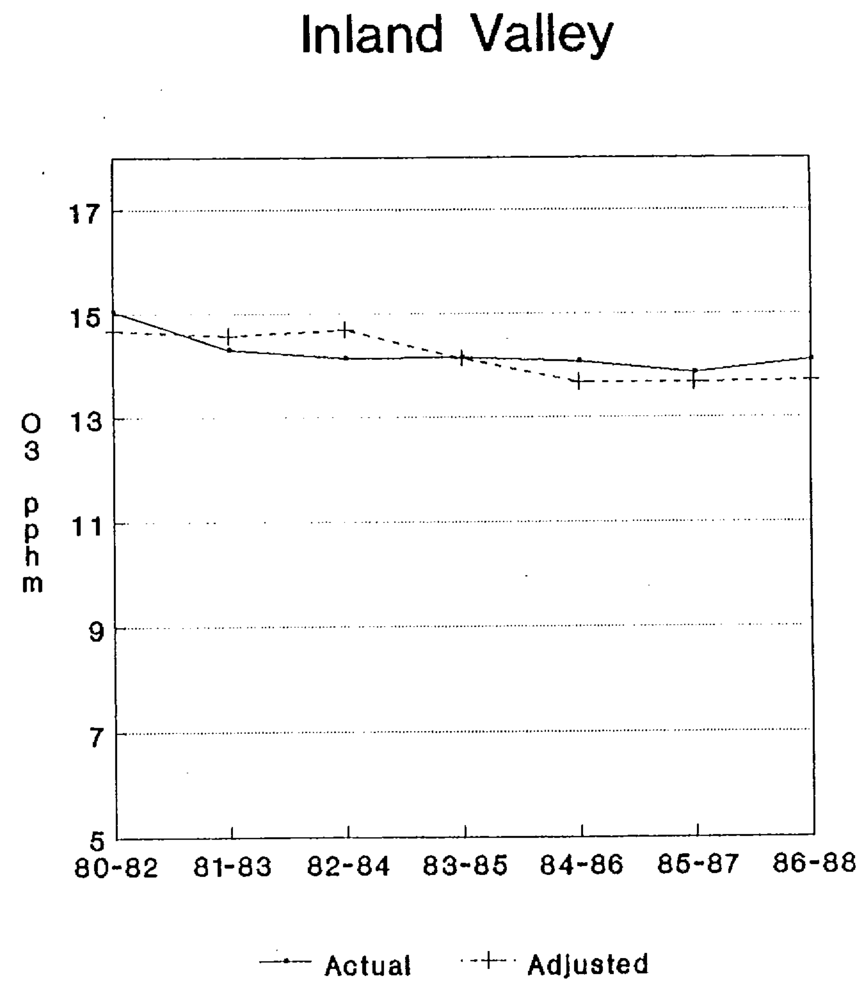

FIGURE 6-3. Concluded.

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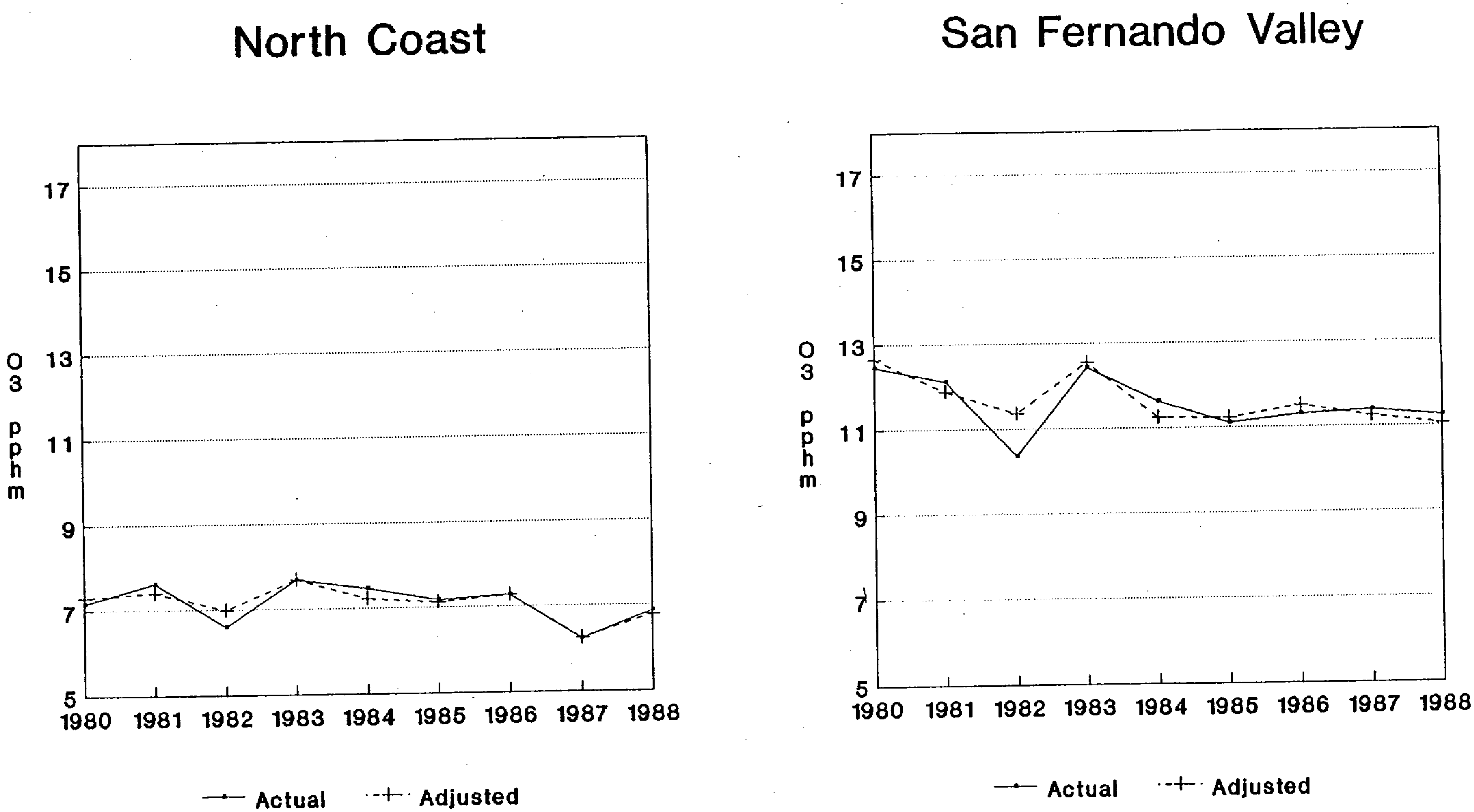

FIGURE 6-4. Seasonal mean ozone concentration trends with 850 mb temperature adjustment applied.

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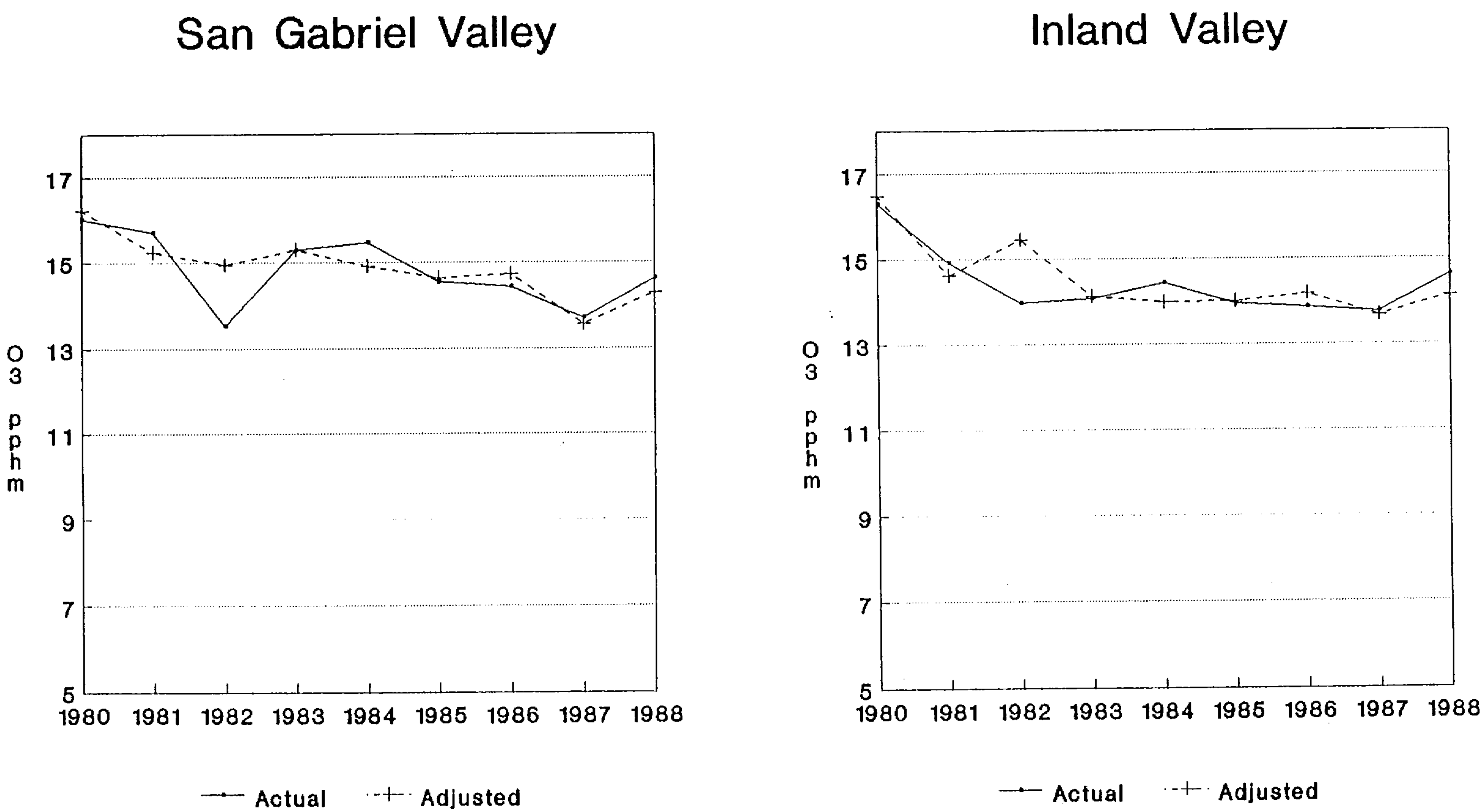

FIGURE 6-4. Concluded.

90028

of the year-to-year variations in the unadjusted values, a fair degree of correlation remains, suggesting that only a small portion of the meteorological variability has been successfully removed.

To compare ozone trends that have been adjusted using the 850 mb temperature method with those adjusted using the meteorological categorization approach, three-year running averages of the temperature-adjusted concentrations were calculated and plotted as shown in Figure 6-5. These results can be compared directly to those in Figure 6-3. In general, Davidson's method leads to adjusted trends that are slightly smoothed versions of the unadjusted values, while the category-based method leads to unreliable adjustments.

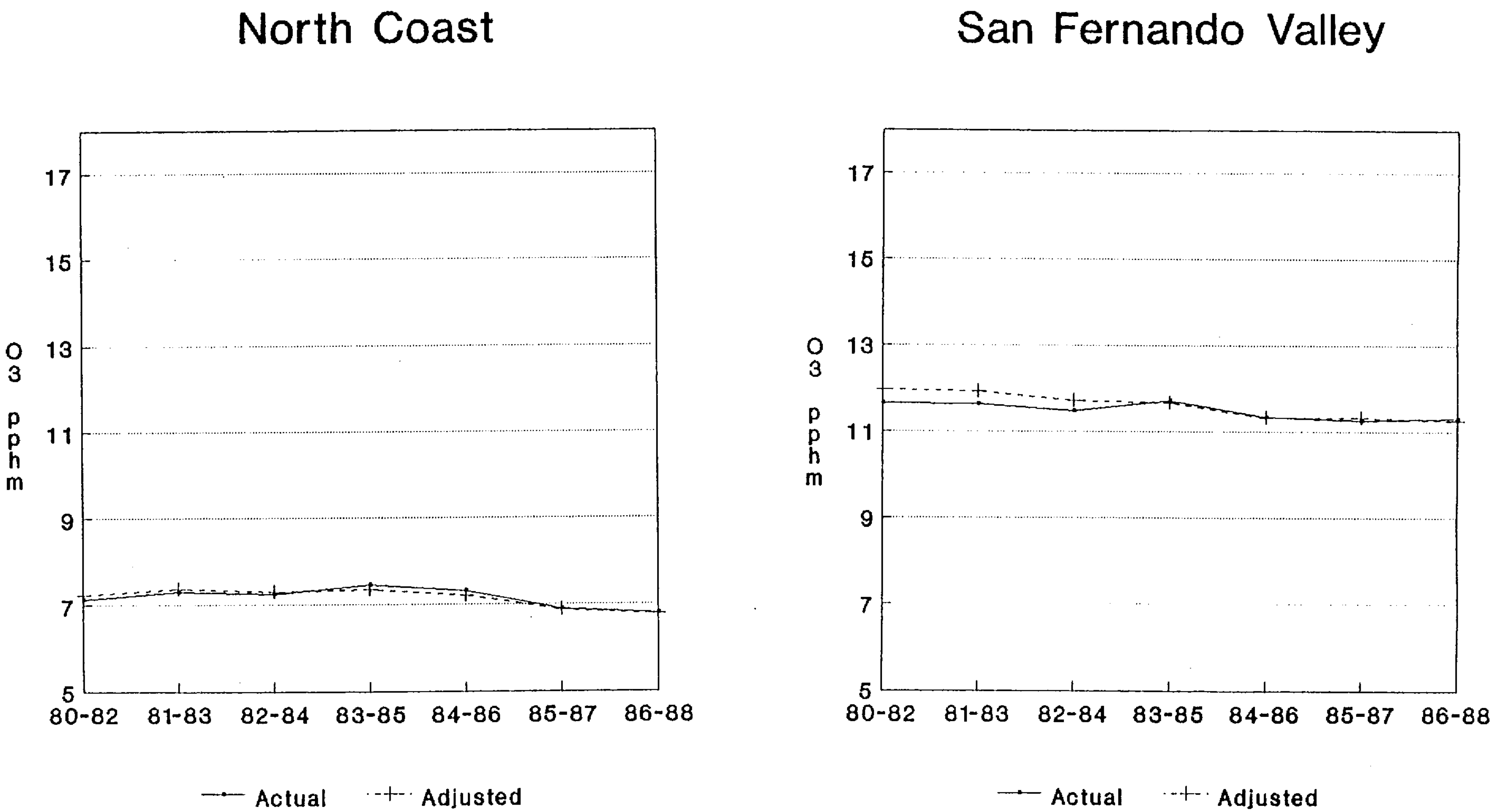

FIGURE 6-5. Three-year running average seasonal mean ozone trend with 850 mb temperature adjustment applied.

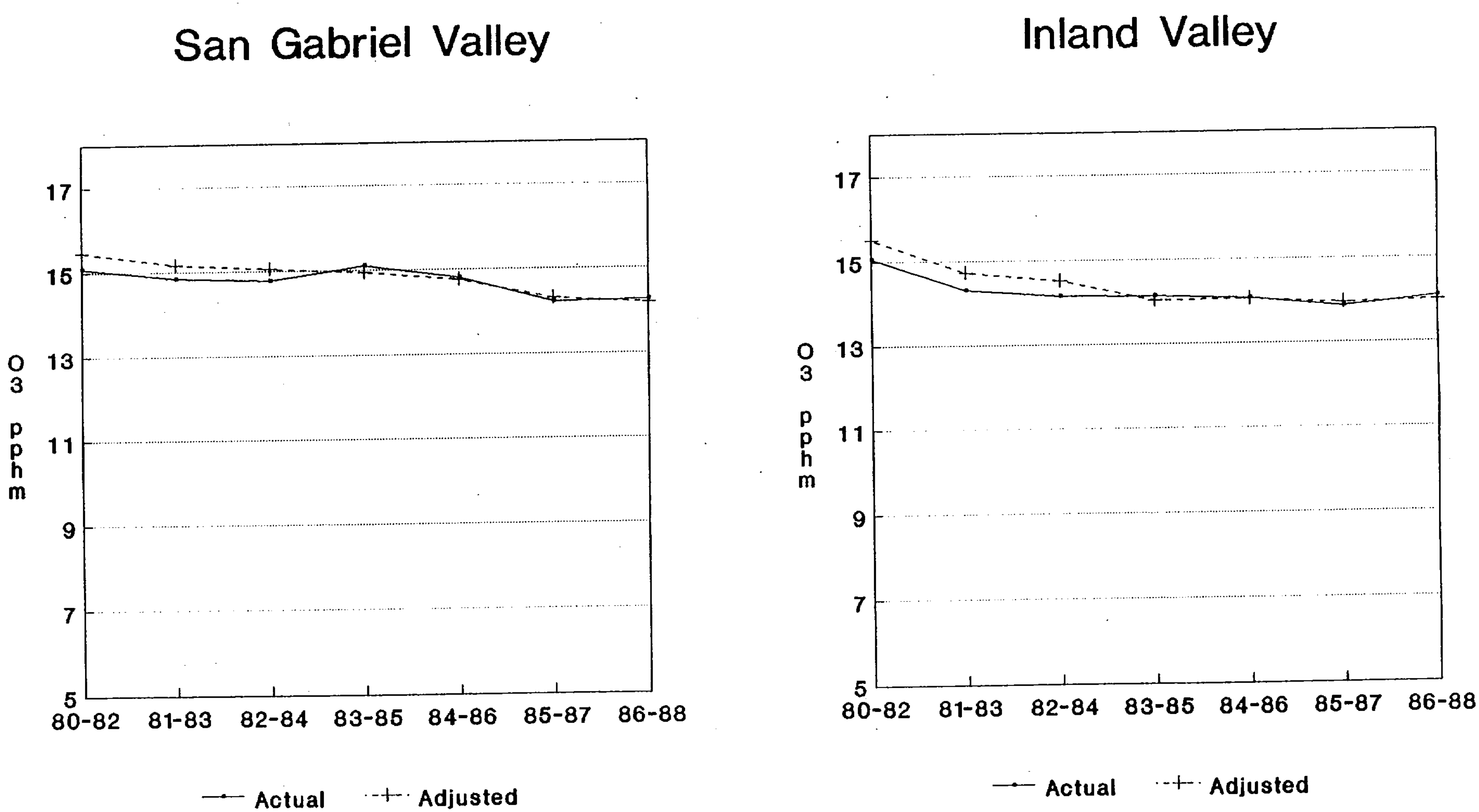

FIGURE 6-5. Concluded.

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7 SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

SUMMARY

Results of the pilot study summarized in Section 4 indicated that at least some of the source history categories identified by Zeldin appear to be associated with distinct and coherent spatial ozone concentration patterns and meteorological features. However, the distributions of concentrations and meteorological parameters exhibited a great deal of overlap from one category to the next, thus making it difficult to clearly identify the unique nature of each of the eight categories Zeldin originally defined based on a preliminary examination of the pilot study data set. In the second part of our study, we undertook analyses designed to provide additional support for the pilot study conclusions by obtaining additional information about the distributions of meteorological parameters and ozone concentrations within each source history category and comparing these distributions between categories. Two aspects of the categories were examined:

Average normalized diurnal ozone concentration profiles were calculated and analyzed for each category. Small but statistically significant differences were found between the profiles representing different categories.

Air parcel trajectories were examined for a set of days selected from each category. Although there is a great deal of variability in the trajectories from one day to the next, many of the trajectories on Eddy days were found to be similar to one another as were many of the trajectories on Partial Southern Route and Southern Route days. The Eddy day trajectories exhibited a characteristic shift in wind direction during the day from east or southeast in the mornings through south to south or southwest in the afternoons. Many of the Southern Route and Partial Southern Route trajectories, on the other hand, showed a shift in wind direction during the morning hours from early morning northerlies to a southwesterly sea breeze regime.

As a result of the difficulties encountered during the pilot study in identifying sufficiently unique meteorological signatures for each source history category, we turned our efforts towards the establishment of meteorological criteria that would allow us to identify the two categories found to be most distinct: Eddy and Southern Route. Rosenbaum (1990) performed extensive analyses of the meteorological conditions associated with these categories, including the examination of numerous surface and upper-air parameters not considered in our pilot study. Rosenbaum succeeded in finding a series of criteria which accurately identify days with spatial ozone patterns that match those associated with Zeldin's Eddy or Partial Eddy and Southern Route or Partial Southern route source history categories. Eddy days were found to be primarily associated with higher sea level pressure to the south of Los Angeles (at San Diego) and lower pressure to the east (at Las Vegas) with southerly component winds along the coast. Southern Route days were found to be primarily associated with higher pressure to the east and lower pressure to the south with northerly component winds at San Diego. Although most days meeting Rosenbaum's criteria had the expected spatial ozone patterns, only about half of all days with such ozone patterns were found to also meet Rosenbaum's criteria. The remaining days, along with days in the Typical, Typical with Eddy Winds and Offshore source history categories, were assigned to an "Uncertain" meteorological category. Although the presence of a large group of days in the Uncertain category is undesirable for some applications, the restrictive nature of Rosenbaum's meteorological classification procedure is useful in the sense that it insures that nearly all of the days which do meet the criteria will exhibit the expected ozone pattern. We therefore adopted Rosenbaum's criteria for use in our study and used them to categorize all days included in the study period (Tuesday - Thursday, May - October, 1980 - 1988).

As a result of the different source histories identified by Rosenbaum's Eddy and Southern Route meteorological categories, we would expect to see differences between the two categories in the relationship between meteorological conditions and ozone concentrations at various locations within the SOCAB. We performed CART and best subsets regression analyses in an attempt to identify which meteorological variables are most closely correlated with ozone concentrations within each category. Although results of the two regression approaches are somewhat inconsistent, temperature variables were found to be closely related to ozone formation in all cases.

A potential use of the meteorological categorization procedure is in the adjustment of ozone concentration trends to account for variations resulting from changes in weather conditions. In the first step of the adjustment process, adjusted values of the mean daily maximum ozone concentration for days within each meteorological category were selected on the basis of a regression analysis. The resulting within-category adjusted concentrations can be interpreted as the values which would have been observed had meteorological conditions within each category corresponded to climatological norms. In the final step of the adjustment process, adjusted seasonal mean concentrations over all meteorological categories were calculated by averaging the adjusted concentrations across categories, assuming that the frequency of occurrence of each category during each 3-year interval is equal to the long-term (9-year) average frequency of occurrence. In this way, the influence on seasonal mean ozone of year-to-year differences in the number of days falling in each category is accounted for and the resulting adjusted concentrations reflect not only the effects of meteorological variations within each category but also between categories.

Unfortunately, the within-category regression equations on which the meteorological adjustment calculations were based proved to fit the data quite poorly in many cases. As a result, the adjusted seasonal mean concentrations were unreliable and the adjusted trends were just as noisy if not more noisy than the unadjusted trends. In addition, much of the year-to-year variability in concentrations was found to be removed simply by the calculation of 3-year running averages, leaving only relatively small variations for the adjustment procedure to eliminate.

We compared results from the category-based trend adjustment procedure described above to results obtained from an alternative adjustment procedure suggested by Davidson et al. (1985). This procedure makes use of the observation that SOCAB ozone concentrations are closely correlated with the morning 850 mb temperature. Results obtained indicate that some of the year-to-year variations in seasonal mean ozone is accounted for by variations in temperature. However, considerable correlation between the adjusted and unadjusted trends remains, suggesting that additional meteorological variability remains unaccounted for. Temperature adjusted trends were compared to those obtained using the category-based adjustment method. This comparison shows that the temperature adjustment method leads to more reliable results.

CONCLUSIONS

On the basis of the results summarized above, it is evident that at least some of the day-to-day variations in meteorological conditions and in the spatial and temporal distribution of ozone in the SOCAB can be accounted for by the grouping of days into source history categories. Furthermore, we have shown that at least two of the source history categories originally identified by Zeldin (Eddy and Southern Route) are characterized by distinct and coherent spatial ozone patterns and meteorological conditions and that these differences characterize two different flow regimes:

> Eddy days are characterized by southerly winds along the coast south of Palos Verdes, higher sea level pressure south of Los Angeles (at San Diego) and lower pressure to the east (at Las Vegas). These conditions are identical to those found by Mass and Albright (1989) to be characteristic of Catalina Eddy events. Basin wide ozone concentrations are lower under these conditions than on other days, apparently as a result of a deepening of the marine layer (thus resulting in increased cloudiness, increased dispersion and increased flow out of the basin of polluted air over mountain passes to the east) as suggested by Mass and Albright and confirmed by our data. Concentrations in the mountains and the San Fernando valley are higher relative to the basin average on these days than under other flow regimes.

> Southern Route days are characterized by weak offshore pressure gradients with higher pressure to the north and east of Los Angeles and lower pressure to the south (at San Diego). This pressure pattern results in a shallow marine

layer and a delayed onset and a weakening of the sea breeze. Air mass residence time is thus increased over the more emission intensive western portions of the basin with minimal mixing, dispersion, and afternoon transport inland. As a result, some of the highest ozone concentrations of the season are observed under these conditions and concentrations in the heavily populated coastal and metropolitan regions are higher in both an absolute sense and relative to the basin-wide average than on other days.

A large proportion of days in each ozone season fail to exhibit some or all of the characteristics of either the Eddy or Southern Route patterns described above. Based on a preliminary analysis of the data used in our pilot study, Zeldin suggested that some of these days could be classified as belonging to a "Typical" source history category. However, we were unable to identify a consistent set of either spatial ozone patterns or meteorological conditions which could be used to characterize such a category. Zeldin also identified an "Offshore" category which appears to be primarily characterized by offshore pressure gradients, high temperatures, little or no sea breeze and relatively high ozone concentrations along the coast. Unfortunately, too few days of this type were found in the pilot study data set to allow for a definitive analysis of how such days might differ from those in the Southern Route category.

Although the Eddy and Southern Route patterns appear to identify distinctly different source history categories, there remains considerable variability in daily maximum ozone concentrations within each of these categories. Despite the fact that the means of the daily maximum ozone concentrations on days within each category are significantly different from one another in a statistical sense, only a small percentage of the variance in subregion average daily maximum ozone concentrations can actually be explained by the grouping of days into the Eddy, Southern Route and Uncertain categories. Temperature (especially the 850 mb temperature) appears to be the single most important factor in accounting for the remaining within-category variability.

Our attempts to use the knowledge of SOCAB source history categories gained in this study to adjust seasonal mean ozone trends to account for variations in meteorological conditions were not successful due to difficulties encountered in developing statistical models that do an adequate job of accounting for within category variability.

RECOMMENDATIONS

Further analyses of the source history characteristics associated with ozone episodes are clearly needed before we can fully understand the complex relationships between meteorological conditions and ozone concentrations in the SOCAB. Therefore, we cannot at this time provide definitive guidance on the selection and application of meteorological trend adjustment procedures or on the development of episode selection criteria for photochemical modeling. With regard to trend adjustment methods, it is evident that the simple procedure developed by Davidson et al. (1985) is the best currently available method for making meteorological adjustments to trends in seasonal mean ozone where the mean is taken over all days (and thus all meteorological conditions). However, differences between source history categories in unadjusted trends such as those shown in Figure 6-1 are of potential significance to air quality planners and should be examined further. In addition, further work on the development of more accurate regression models to be used for calculating adjusted within-category trends should be pursued.

With regard to episode selection criteria, the results of this study support those of previous studies in showing that high ozone concentrations can occur in the SOCAB under quite different meteorological scenarios. At this time we are only able to clearly identify two such scenarios (Eddy and Southern Route), and, given the generally lower concentrations associated with Eddy days, the regulatory significance of this category is unclear. A better understanding of the conditions associated with high ozone days that did not meet the Eddy or Southern Route meteorological criteria is needed. One approach to this problem is to perform case studies of the meteorological conditions on several such days.

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